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The Limnology of Williston Reservoir

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A. East shoreline, Finlay Reach, with woody debris, Williston Reservoir, July 1999

B. East shoreline, Finlay Reach with woody debris and barren, slumping and eroding littoral zone, July 1999.

C. Primary production incubation set suspended between floats, Forebay Station, July 1999. W.A.C. Bennett Dam in background.

ABSTRACT

Limnological studies were conducted on Williston Reservoir in 1999 and 2000, as part of a 2-yr intensive monitoring program whose purpose was to establish a uniform, reliable physico-chemical and biological database to enable reliable assessments of future changes within the reservoir and to forecast ecosystem production for fisheries management. This final report summarises results of the limnological data gathered during the 2-yr monitor.

The reservoir has shown remarkably little spatiotemporal variance among variables and basins, this despite the biogeoclimatic complexity and diversity of landscapes inundated, and the immense size of the system's drainage basin. Average concentrations of total dissolved phosphorus (TDP 3-5 mg/m^3) and nitrate nitrogen (NO_3-N 60-65 mg/m^3) were similar between years and values of their ratio (TDP:NO_3-N) suggested no serious nutrient limitation of phytoplankton growth except in the Finlay Reach where in late summer values of NO_3-N were below detection levels in both years. Phytoplankton and zooplankton communities showed some inter-annual variability, with higher abundance and biomass values in 1999 than in 2000. Seasonally, the lowest abundance and biomass occurred in the spring and highest in late summer and early autumn. The pelagic plankton community composition was very similar to those found in other oligotrophic BC lakes, with a preponderance of small autotrophic picoplankters, nano-flagellates and small diatoms in the phytoplankton community, and with the zooplankton community dominated by copepods and in late-summer by cladocerans. Microbial food webs are predominant in Williston through much of the growing season, with small pico- and nano-plankton as primary autotrophs. Microbial communities lead to multiple pathways of carbon flow that are less efficient in transferring carbon to higher trophic level, further reducing potential fish production. Using mean values of TDP and chlorophyll from the 1999 and 2000 monitor enabled comparison with earlier nutrient data that indicated Williston Reservoir after impoundment in 1968 was initially a moderately productive ecosystem, but the system has progressively lost nutrients (P) through sedimentation and outflow, and this decline has been exacerbated by the loss of littoral zone carbon production due to winter drawdown. Thus, over the past 2-3 decades the system has slowly lost productive capacity and now lies within the 'very low' production or **ultra-oligotrophic** range. Primary production rates are very low and appear to be limited primarily by low light imparted by turbidity and frequent deep mixing episodes. Daily carbon (C) production values are much lower than most interior BC lakes, and are now at levels more typical of 'ultra'-oligotrophic coastal BC lakes. Using new estimates of daily primary production obtained monthly in year 2000 and a photosynthetic rate (PR) based model we computed for the first time an estimate of Williston's rearing capacity for pelagic planktivorous fishes. Estimates from the model show that the Finlay Reach is currently the most productive sector or sub-basin of the reservoir for pelagic and benthic fish production, followed by the less productive Peace and Parsnip reaches.

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INTRODUCTION

Background & Scope

The Williston monitoring program was developed to gather salient limnological information required for the determination of the current trophic status and productive capacity of the reservoir. Numerous past limnological studies (BC Research 1976, 1977; Barrett and Halsey 1985; Fleming et. al. 1991 unpublished data; G3 report Vol. 1 1996) have gathered data and reported on water quality and status of biotic resources including fisheries potentials, but frequent inconsistencies in such factors as locations of sample stations, in depths and times sampled, in physico-chemical variables examined, in sampling methods used and differing analytical chemistry laboratories, has created considerable variance in reported results. These inconsistencies have made comparisons with previous studies very difficult, and have questioned the validity of interpretations.

The 1999-2000 Williston Reservoir Monitor (WRM) program established *permanent* sampling stations, and registered them with the Environmental Monitoring System (EMS) database, administered by Water Management Branch, Ministry of Environment, Lands and Parks (MOELP). The establishment of 5 permanent sampling locations, will foster the need for consistency in all future studies, enabling more meaningful comparisons in future without the uncertainties of station location and methodological differences. It is the WRM program's intent that future Williston Reservoir monitoring programs will replicate sampling station locations, methods and analytical protocols used here, thus enabling a more reliable means of assessment of changes in Williston's productive capacity, and what the implications of any changes might mean to food chains and fisheries resources.

Study objectives

This final report presents limnological results obtained during the open-water (growing season) period in Williston Reservoir in 1999 and 2000. Information gathered during this 2-yr monitor will be used to estimate the current trophic status and productive capacity of the reservoir. The current status of Williston will be compared and contrasted with recent limnological data from other large BC lakes and reservoirs, and using primary production data obtained in 2000, estimates will be made of the carrying capacity of the major basins of the reservoir for pelagic fishes (kokanee, whitefish), using a recently developed photosynthetic rate (PR) based model (Shortreed et al. 2000).

DESCRIPTION OF STUDY AREA

Williston Reservoir (56° N latitude, 124° W longitude) is located approximately 140 km north of Prince George in northeast British Columbia, Canada (Fig. 1). The reservoir was created in 1968 by impounding (W.A.C. Bennett Dam) the Peace River in the canyon near Hudson's Hope, B.C. for hydroelectric generation. A second dam, Peace Canyon, is located 22 km downstream of the W.A.C. Bennett Dam. The Peace Canyon Dam impounds water to the base of the W.A.C. Bennett Dam, thereby forming Dinosaur Reservoir.

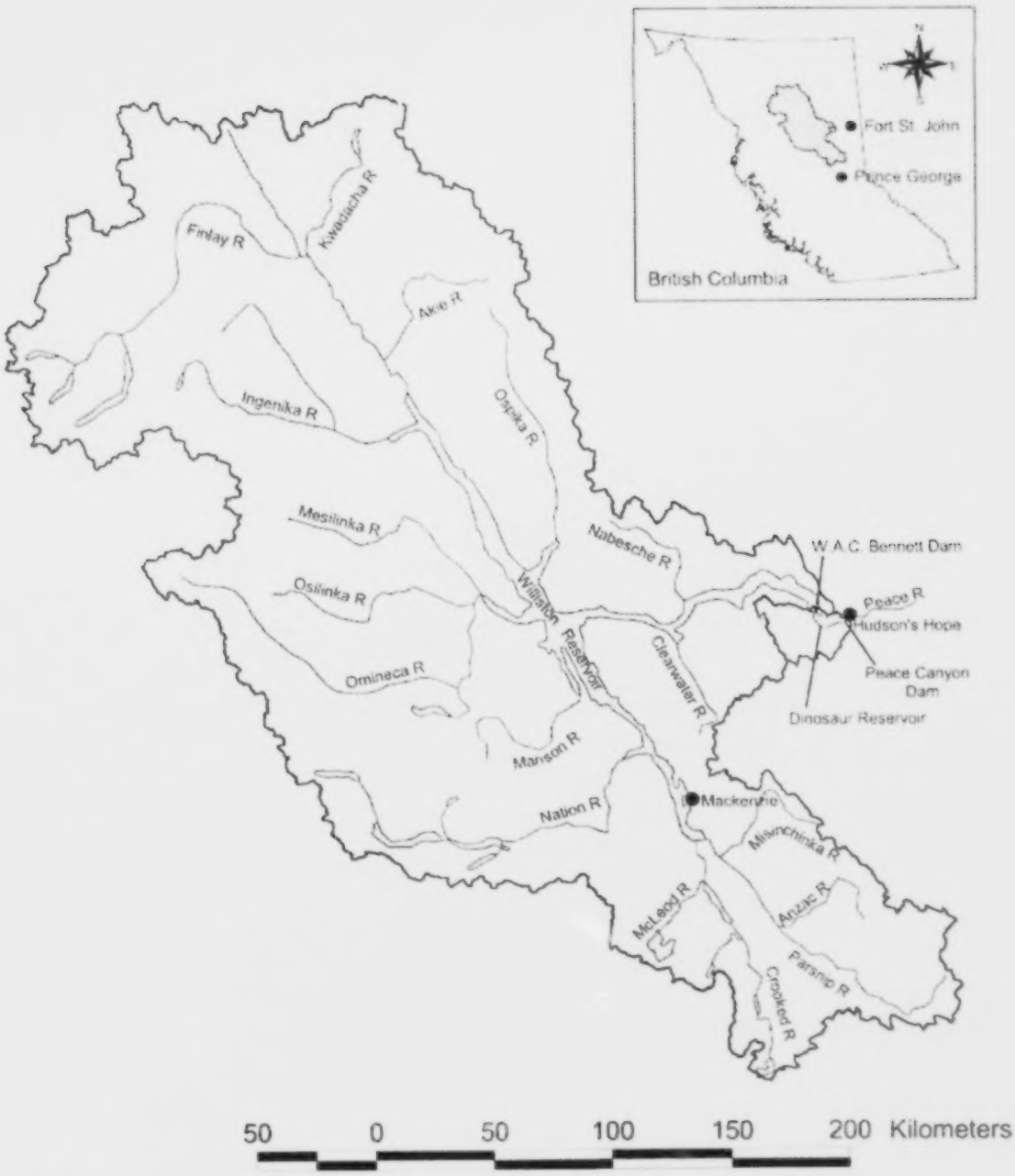
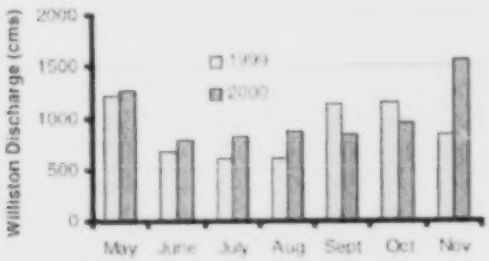


Figure 1. Williston Reservoir Watershed

Dinosaur Reservoir is operated as a "run of the river" hydroelectric project with minimal (1-2 m) water level fluctuations. The Peace River flows east to Lake Athabasca within the Mackenzie River drainage system, which flows north and discharges into the Arctic Ocean.

The W.A.C. Bennett Dam inundated the upper Peace River canyon creating the **Peace Reach** that extends westward approximately 120 km to 'junction' with the confluence of the **Parsnip** and **Finlay reaches.** From the Junction the Finlay Reach (previous Finlay River basin) extends in a northwest direction about 120 km, and the Parsnip Reach (previous Parsnip River basin) extends in a southeast direction for approximately 110 km (Fig. 1). Discharges (outflow) from the Bennett Dam during the ice-free period during the period of this 2- year monitor are presented in Fig. 2.

Fig. 2. Williston Reservoir mean daily discharge during ice-free period of 1999 & 2000.



The Williston Reservoir drainage basin encompasses 5 biogeoclimatic sub-zones: sub-boreal spruce, Engleman spruce - subalpine fir, boreal white and black spruce, and spruce-willow-birch and alpine tundra (BC Hydro 1988). The Omineca mountains to the west, and Rocky mountains to the east contain the generally north to south lying Finlay and Parsnip reaches within a wide, flat-bottomed valley of the Rocky Mountain Trench. Glacial deposition, moraines and lacustrine deposits are common (Fleming et al. 1991, unpublished data), and glacial till is the most abundant surficial deposit found within the drainage basin (Ministry of Environment 1983). The Peace Reach has a "V" shaped basin and is much narrower and deeper than either the Finlay or Parsnip reaches. Steep-sloped sedimentary rock is predominant in the entrenched western half of the Peace Reach where the Peace River originally (prior to impoundment) cascaded eastward breaking through the Rocky Mountains. The eastern half of the Peace Reach extends into the Rocky Mountain Foothills, and contains lower gradient topography and geological features quite similar to those of Finlay and Parsnip reaches.

The Williston watershed is subject to a continental climate with long, cold winters. Temperatures as low as -30° C can occur anytime after October, with sub-zero temperatures often extending into April. Frost may occur at any time of the year (Maclean 1998), and ice formation on the reservoir can begin as early as November, though complete coverage usually does not occur until January. Ice cover can be

delayed, as occurred during the winter of 1999 and 2000, or can be incomplete in uncommonly warm winters. The area in front of the Dam (forebay) is generally the last area to freeze. Ice cover normally extends to approximately the first week of May. The Finlay Reach is generally the last area be completely ice free. The summer average air temperatures range from 16° C to 18° C, with maximum temperatures reaching 30° C (G3 Consulting Rep. 1994). Annual precipitation ranges between 40 - 50 cm in most of the catchment basin, with the exception of greater amounts (75 - 100 cm) in the Rocky Mountains east of the Finlay Reach (BC Hydro 1988), and snowfall accounts for 35 to 45% of the total annual precipitation.

Williston Reservoir experiences a harsh, continental climate, and has a dimictic circulation pattern, characterized by 2 distinct periods of deep-mixing, one in spring and another in late autumn. These two mixing periods are often referred to as spring and fall 'transition' periods. Spring winds are usually sustained and sufficient in strength to maintain isothermal temperatures in the water column for several weeks in May before stratification commences. The onset of thermal stratification, with a discernable epilimnion, metalimnion and hypolimnion usually occur in most basins of Williston by late May or early June, and usually lasts well into October or early November and the beginning of major winter storms. Stratification is weakest and shortest in duration in the shallow Finlay and Parsnip reaches and strongest and longest in the much deeper Peace Reach. In winter from late February and lasting until ice-out in early May the reservoir shows a typical 'inverse' stratification, with colder and less dense 1-2° C water on top of dense 4° C water extending to the bottom.

The reservoir has a mean depth of 44 m, and a maximum depth of 166 m (BC Research 1977). The shoreline of Williston Reservoir is dendritic in shape and estimated to be about 1,770 km in length (BC Research 1977). With a surface area (SA) of 1,779 km^2 at a maximum, normal operating level of 672.1 m (BC Hydro 1988), Williston Reservoir is the largest lentic fresh water system in British Columbia. The catchment area (CA) of the Williston drainage basin is 69,930 km^2, equal in size to the province of New Brunswick (BC Hydro 1996), and accordingly the catchment to surface area ratio (CA/SA) for Williston Reservoir is also very large - 39:1. The reported average water residence time of the reservoir varies from 19 months (Hirst 1991) to 2.2 years (Fleming et al. 1991, unpublished data). With a storage capacity of 74,257 x 10^6 m^3 of water, Williston Reservoir by volume is ranked the ninth largest reservoir in the world (Maclean 1998). The reservoir receives and stores most of its hydrologic input from snowmelt and a large spring run-off that peaks in late May and early June.

The reservoir cycles between maximum and minimum levels once per year, typically reaching a maximum level in August and September at 672.1 m Maximum Normal Level (MNL) above sea level. Increased discharge and low winter inflow result in deep winter draw down, averaging 11 m/yr attained in April or early May (Hirst 1991). Power generation in response to electricity demand is highest in the winter and lowest in summer. There are 10 intakes at the face of W.A.C. Bennett Dam. The 3 deepest take mainly hypolimnetic water from 77.6 m below MNL, but the 7 shallower intakes at 44 m below MNL can potentially withdraw epi- or meta-limnetic water. Small whirlpools that are often seen at the surface in front of the shallower intakes would suggest water withdrawal from the entire water column. The discharge water temperatures indicate a mix of hypolimnion and epilimnetic water withdrawal.

Present state of the reservoir.

The impoundment of the Peace River created BC's largest lake/reservoir system where only large rivers existed previously. The inundation of approximately 1,700 km^2 of previously forested land that was only minimally harvested prior to flooding, created a sudden and major release of nutrients to the new reservoir resulting in artificially high production levels over the first 5-10 yrs, i.e. the reservoir's ***'boom'*** period. But this biogenic source of nutrients from flooded landscapes was finite, and after 15-25 yrs the reservoir has gradually lost most of these nutrients, notably phosphorus (P), either by sedimentation (adsorption to Fe-P and Al-P in surficial sediments) or to outflow. The reservoir also loses large amounts of biogenic carbon production because of a non-functional littoral zone caused by erosion. The erosion is created by large annual water level fluctuations (11m average) and ice scour due to winter drawdown. Collectively, these losses outweigh nutrient inputs from natural sources and a process of gradually declining biogenic production begins i.e. oligotrophication, i.e. the ***'bust'*** period (Stockner et al. 2000). This type of 'boom' and 'bust' cycle is particularly evident in newly created 'riverine' valley reservoirs such as Williston. Aging of 'new' reservoirs to the point of equilibrium with nutrient input/output usually requires 20 to 30 yrs. Based on an analysis of nutrient data from 1975 and 1988, Stockner (1998, BC Hydro Report) considered the present trophic status of Williston Reservoir to be oligotrophic, but whether the system had attained equilibrium with nutrient supplies in each of the 3 major basins after 30 yrs could not be discerned without further study (see Stockner and Langston 2000). Nutrient data from the current monitor program now suggest equilibrium conditions with some consistency of the mass balance of annual nutrient input/output and sedimentation and discharge.

METHODS

Stations and Sampling.

To enable future repeatable sampling, five permanent stations have been established. Site selection criterion included proximity to past research sampling locations, positioning over the original inundated river channels to achieve maximum depth, and distancing the location from any major turbidity input sources (river mouths, eroding alluvial shorelines, etc.). Five stations were selected, 3 located within the deepest part of each major basin (reach) of the reservoir - Finlay Reach, Parsnip Reach, and Peace Reach (Clearwater) stations; and 2 in zones of special interest - the "Junction" and the "Forebay" stations (Fig. 3). The Junction station is situated near the old confluence of the Finlay and Parsnip rivers and the western origin of the Peace Reach, and this station was selected to represent a transition/mixing zone where Finlay and Parsnip waters are mixed and begin flowing eastward. The first Peace Reach station is located at 'Clearwater' about 50 km east of Junction and the second, the "Forebay" station is located approximately 2 km west of the W.A.C. Bennett Dam in one of the deepest parts of the reservoir. A sixth, nutrient sampling *only* station is located on the north bank of the Peace River 500 m downstream of Peace Canyon Dam. The data collected at these sites has been entered into the Environmental Monitoring System

Figure 3. Location of sampling locations.

(EMS) database. The EMS designation and co-ordinates (NAD 27 datum) for the sites are:

Parsnip Reach (EMS 234185), UTM co-ordinates 10.458200.6175500
Finlay Reach (EMS 234184), UTM co-ordinates 10.410111.6252000
Junction Station (EMS 234187), UTM co-ordinates 10.452000.6211550
Peace Reach (EMS 234186), UTM co-ordinates 10.486000.6204000
Forebay Station (EMS 234188), UTM co-ordinates 10.550204.6210540

Sampling trips were conducted at the beginning of each month, beginning in May and continuing to the end of November 2000. A single winter sampling trip was done in March 1999, through the ice at the "Forebay" station. All Williston Reservoir stations were accessed by boat, and the Peace River station below W.A.C. Bennett Dam was accessed by vehicle. The Finlay Reach station was not accessible in May 1999 due to extensive ice cover. The Finlay and Parsnip reach stations were also not accessible in November 1999 owing to high winds and unsafe water conditions. All stations and depths were successfully sampled monthly in 2000.

Physico-chemical.

A YSI model 58 oxygen/ temperature meter was used to collect dissolved oxygen (PPM or mg/L) and temperature (°C) at depth (m). A 20 cm standard Secchi disc vertically cast from the shaded side of the boat was used (without viewing chamber) to indicate Secchi depth, or water transparency. Water depth was measured with a digital Hummingbird depth sounder and recorded to the nearest meter. Cloud cover was estimated and recorded to the nearest 10 percent. In 2000 light attenuation (extinction coefficients) and compensations depths (1% of surface intensity) were estimated from vertical light profiles obtained at each station using a Li-Cor submersible quantum sensor (400-700 µm, Model Li 192s). The natural logarithm of light intensity was plotted against depth and a line fitted to points by linear regression provided and estimate of the mean downward extinction coefficient, *k*. Total daily solar radiation was measured at Finlay Landing in close proximity to Junction Station using a Model 190s Li-Cor quantum sensor. Reservoir elevation data was provided to the nearest 0.1 m by BC Hydro W.A.C. Bennett Dam operational staff.

Water samples were collected with a vertical Alpha water bottle (Van Dorn sampler). Samples were shipped in dark, ice filled containers, and analyzed within 96 hrs of collection. Analyses of most water samples were conducted at Environment Canada's Pacific Environmental Science Centre (PESC) laboratories in North Vancouver, B.C. Laboratory methods employed at PESC follow guidelines established by McQuaker (1994) in -***'British Columbia environmental laboratory manual for the analysis of water, wastewater, sediment and biological materials'.*** Water samples to determine alkalinity for C^{14} production analysis were analyzed at the University of British Columbia, Environmental Engineering Laboratory, Vancouver BC.

A pHep model 3 digital hand-held pH meter provided "field" pH measurements. Water samples collected for chlorophyll-a content were field filtered through a 0.45 µm cellulose acetate filter at a maximum vacuum of 18 cm Hg. The filter was then frozen, stored and submitted for lab analysis at the end of each sampling trip. Water samples collected for low level phosphorus determination (TDP) were field filtered with a 0.45

µm filter cartridge at low vacuum pressure and the filtrate submitted for analysis. Quality control/assurance of laboratory analysis was provided by the Pacific Environmental Science Center's internal quality assurance program. Additionally, 10% of water samples collected for nutrient level analysis and approximately 25% of samples collected for chlorophyll-a analysis were replicated for comparison of results.

Phytoplankton.

When conditions permitted, a 250 ml sample of water from 1, 3, and 5 m depths was obtained monthly from May to November from each of the 5 stations. Each phytoplankton sample was preserved in acid Lugol's iodine preservative and stored in a cool location until analysis. Prior to quantitative enumeration by the Utermohl (1958) method samples were gently shaken for 60 seconds, carefully poured into 25 mL settling chambers and allowed to settle for a minimum of 24 hr. Counts were done using a Carl Zeiss inverted phase-contrast plankton microscope. Counting followed a 2-step process: 1.] random fields (5 -10) were examined at 250X magnification (16X objective) and large micro-phytoplankton (20-200 µm), e.g. diatoms, dinoflagellates, filamentous blue-greens, were enumerated, and 2.] cells within a random transect (ranging from 10 to 15 mm) were counted at 1,560X magnification (100X objective). This high magnification permitted quantitative enumeration of minute (<2 µm) autotrophic picoplankton (APP) cells (0.2-2.0 (µm) [Class Cyanophyceae], and also of small auto-, mixo- and heterotrophic nano-flagellates (2.0-20.0 µm) [Classes Chrysophyceae and Cryptophyceae]. In total between 250-300 cells were consistently enumerated in each sample to assure statistical accuracy (Lund et al. 1958). The compendium of Canter-Lund & Lund (1995) was used as the taxonomic reference. The list of phytoplankton species for Williston Reservoir in 1999 and 2000 with their respective biovolumes used for the computation of population and class biovolume estimates for are given in Appendix A.

Bacteria and autotrophic picoplankton (APP).

Water samples from 1, 3 and 5 m depth were mixed and 2, 15 mL sub-samples obtained monthly from May to November 2000 from each of the 5 stations for analysis of bacteria and autotrophic picoplankton (APP). Bacteria samples were preserved with 3 drops of gluteradehyde and placed in a sterile capped test-tube, and another 15 mL were filtered onto pre-stained Irgalen black 0.2 µm polycarbonate Nuclepore filters and placed in an envelope and stored in a cool location until microscopic analysis. Bacteria and APP densities were determined at the University of British Columbia (UBC), Plankton Ecology Laboratory, using both the acridine orange and DAPI stained direct count epifluorescence method described by Maclsaac et al. (1981). Random fields were counted at 1,250x magnification oil immersion after filtration of 10-15 mL samples onto 0.2 µm Irgalen black stained filters using a Zeiss epifluorescence microscope and blue-band excitation filter at wavelengths of 450-490 nm. APP were enumerated using the epifluorescence method described by Maclsaac and Stockner (1985). Up to 30 random fields were counted using a wide-band filter excitation (397-560 nm). Bacteria and APP densities are reported as cells/mL.

Zooplankton.

Sampling occurred monthly at each station between May and November each year (June-October for Finlay in 1999 because of ice cover). At each station, duplicate macrozooplankton samples were collected with a vertically (0-30 m) towed, 80 μm mesh Wisconsin plankton net, with a 50 cm throat diameter, and a 74 (μm mesh window for straining water from the collection cup. The net was raised at a speed of approx. 0.5 m/sec. Before preservation with 70% ethanol, samples were placed in 4% $NaHCO_3$ to prevent egg loss with addition of ethanol. Samples were analysed for species composition, density, biomass, and fecundity in the following manner. The total volume of the sample was measured, stirred, split with a Folsom splitter to a volume that contained not less than 100 post naupliar stages of the most abundant taxa. A random sub-sample comprising a known proportion of the sample was then enumerated for species, size, sex, stage of maturity and reproductive condition. Fecundity of the dominant genera was estimated by counting the number of eggs of the first ten gravid females counted. Enumeration was conducted on a gridded petri-dish using GSZ Zeiss Stereo microscope under suitable magnification (10-100X). Additional examination of crucial body parts was done using an inverted microscope and magnification up to 400X. The entire sample was also examined for large organisms (e.g. *Leptodora kindti)* that are not efficiently sub-sampled.

Adult calanoid copepods were identified using Wilson (1959), and adult cyclopoids following Yeatman (1959). Cladoceran identifications followed Brooks (1959) and Deevey and Deevey (1971), but with the observed *Eubosmina longispina* resembling those described by Brooks as *Bosmina coregoni.*

Biomass estimates were made by first measuring body length (to nearest 0.01 mm) for a maximum 10-15 individuals from each group (male, female, gravid female, juvenile copepodite, nauplii) present in the sample. Cladoceran body length was measured from the anterior end of the carapace to the base of the tail spine. Copepods were measured from the anterior end of the metasome to the posterior end of the urosome, excluding the caudal rami. Lengths of individual zooplankters were then converted to body mass (μg dry weight) using length-weight relationships developed for each species by McCauley (1984). If an equation was not listed for a species an equation from a similarly shaped species was used, and those substitutions were as follows; The equation for *Diaphanosoma brachyrum* was used for *D. leuchtenbergianum,* the equation for *Daphnia galeata* was used for *D. longiremis,* the equation for *Leptodiaptomus gracilis* was used for *Diacyclops bicuspidatus thomasi, Heterocope septentrionalis* and *Epischhura nevadensis,* and the equation for *Leptodiaptomus sicilis* was used for all the *Leptodiaptomus* species. Species biomass was then computed from the number of individuals in each group multiplied by their arithmetic mean body mass.

Primary Productivity.

Primary production experiments to estimate phytoplankton photosynthetic rates (carbon (C) production) were done in July and September 1999, and monthly from May to November in 2000. Samples in July 1999 were collected at the Forebay and Junction stations, but due to high winds neither the Parsnip nor Finlay stations could be sampled. Instead water was collected at locations several kilometres within each reach, and

production 'only' stations were arbitrarily identified as W2 and W1 respectively (Fig. 3). In September water for primary production estimates was gathered from 4 of the 5 EMS stations, the exception being the Peace Reach station (EMS E234186).

Primary productivity was estimated by using the $H^{14}CO_3$ (carbon labeled bicarbonate) method (Strickland 1960). Water samples were collected from 1, 3, 5 and 7.5 m and transferred to three, 300 mL BOD (Biological Oxygen Demand) bottles. The 2 clear bottles allowed light to penetrate and photosynthesis to occur, while the 3rd dark bottle excluded light and measured dark uptake or respiration. Each of the sample bottles in 1999 was inoculated with 1mL of 3.7 µCIE/ml ^{14}C-HCO_3. This was increased to 5.0 µCIE/ml ^{14}C-HCO_3 in 2000. After inoculation sample bottles were lowered to their respective collection depths and incubated for 2-3 hrs. Incubation was initiated as close to 1000 hrs as possible, but no later than 1300 hrs.

The water samples were retrieved after incubation and stored in a light-tight metal box to prevent further exposure to light. Within 3-4 hrs the samples were filtered through a 0.45 µm, 47 mm diameter cellulose nitrate membrane filter. The filters were transferred to scintillation vials and 4 drops of 6 N HCL were added to each filter. The vials were shipped to the Radiation Laboratory, University of British Columbia Medical School, for analysis of beta activity on a Beckman© *Beta* scintillation counter using standard counting protocols.

Fish.

Williston Reservoir fish species composition and abundance in the pelagic zone was assessed using a combination of hydroacoustic, trawl and gill net sampling (Figure 4). Hydroacoustic data was collected by BC Fisheries staff (D. Sebastion and G. Scholten) August with a Simrad EY200P/Hadas 70kHz echosounder system and a Simrad EY500/EP500 120 kHz split beam system. Night-time hydroacoustic surveys were completed during the new moon period of August, 2000, in order to take advantage of stable weather, lengthening nights and thermal stratification of the reservoir. Trawl netting was completed by contract to Kootenay Wildlife Services, and was undertaken concurrently with the hydroacoustic surveys. Gill netting (over night net sets) was completed by consultants (BCCF and Diversified Environmental Services) concurrent with the hydroacoustic and trawl surveys.

Twenty two species of fish are known (confirmed) to inhabit the Williston watershed; Arctic grayling *(Thymallus arcticus)*, bull trout *(Salvelinus confluentus)*, brassy minnow *(Hybognathus hankinsoni)*, brook trout *(Salvelinus fontinalis)*, burbot *(Lota lota)*, Dolly Varden *(Slavelinus malma)*, kokanee *(Oncorhynchus nerka)*, lake chub *(Couesius plumbeus)*, lake trout *(Salvelinus namaycush)*, lake whitefish *(Coregonus clupeaformis)*, large scale sucker *(Catostomus macrocheilus)*, longnose dace *(Rhinichthys cataractae)*, longnose suckers (Catostomus catostomus), mountain whitefish *(Prosopium williamsoni)*, northern pikeminnow *(Ptychocheilus oregonensis)*, peamouth chubb *(Mylocheilus caurinus)*, prickly sculpin *(Cottus asper)*, pygmy whitefish *(Prosopium coulteri)*, rainbow trout *(Oncorhynchus mykiss)*, redside shiner *(Richardsonius balteatus)*, slimy sculpin *(Cottus cognatus)*, and white sucker *(Catostomus commersoni)*. All 22 species except brook trout could be encountered in Williston Reservoir.

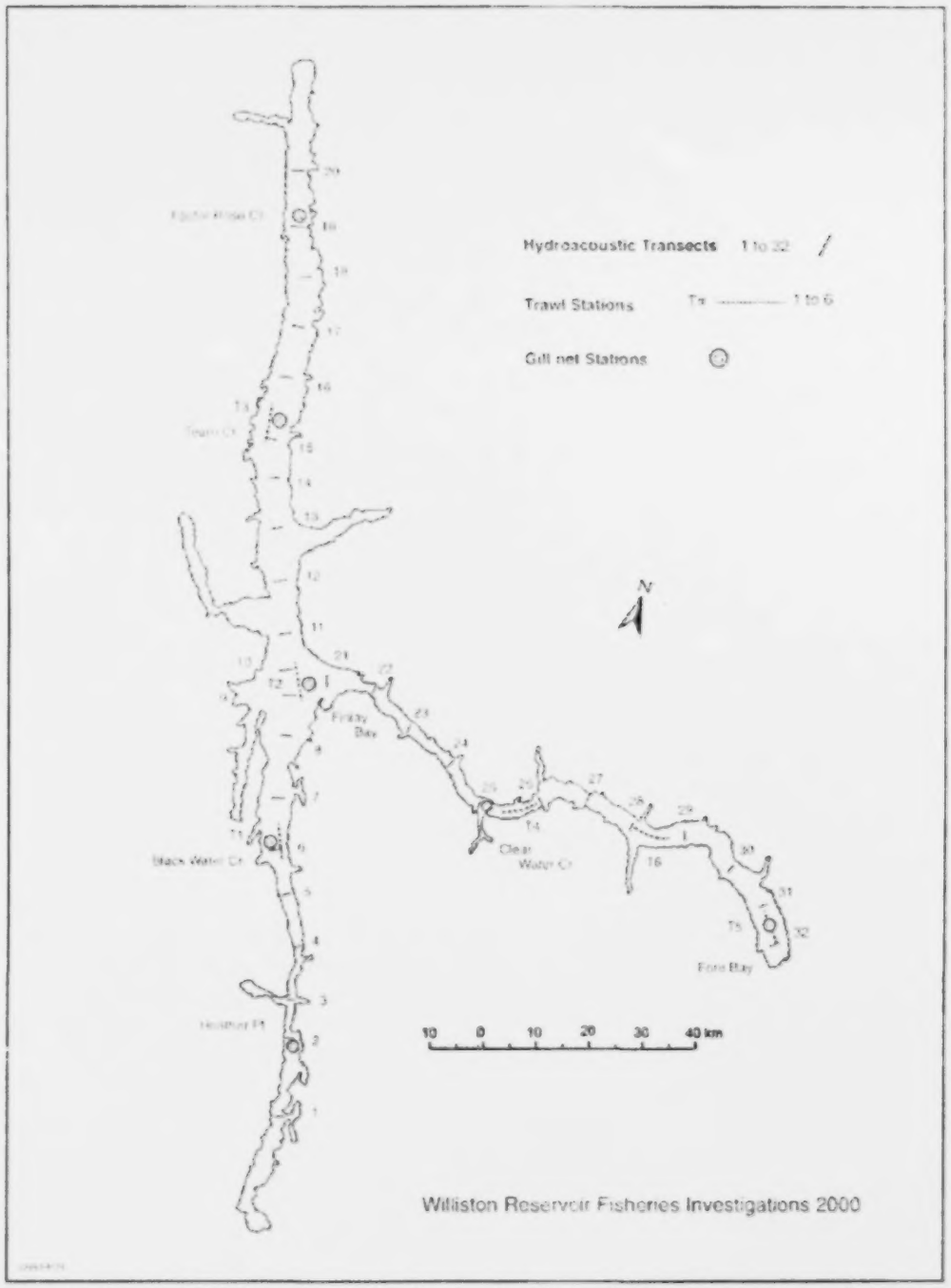


Figure 4. Map of Williston Reservoir showing locations of acoustic transects and trawl survey stations during August 2000. (Courtesy of G. Scholten, BC Fisheries)

RESULTS

Physico-chemical.

Temperature **(Appendix B)** The Williston Reservoir is a dimictic system, with two periods of deep mixing in early May (spring) and November (fall) separated by 2 periods of stratification, one in summer (June-October) the other under ice in early spring (February to April). Open-water stratification commences in June at all stations and lasts to late October and early November. The epilimnion depth is variable, depending on duration and strength of wind episodes, but on average ranges from only 15-25 m in the Parsnip Reach, > 35-40 m in the Peace Reach, and at the Junction and in Finlay Reach is intermediary ranging between 20-30 m. Maximum temperatures are attained in July/August and range from a low of 13° C in the Peace Reach - Clearwater to a high of 19°C at Forebay station. Hypolimnetic temperatures were fairly constant throughout the reservoir, ranging from 4-6° C.

Oxygen **(Appendix B)** Dissolved oxygen profiles in Williston are orthograde, typical of low production oligotrophic lakes, with concentrations at depth showing a uniform distribution and little variation at most stations. Oxygen values at most depths were near saturation with respect to temperature and pressure. There were no discernible zones of reduction (oxygen deficits) or super-saturation peaks in the region of the metalimnion or in the hypolimnion to suggest the prevalence of either high phytoplankton production and/or a zone of reductive assimilation. The only exception to the above trends occurred at the Forebay station where values a few metres above the sediment surface abruptly declined. In 2000 the oxygen profiles at all stations were similar to those seen in 1999, with no notable changes from the above noted trends.

Water transparency (Secchi depth, extinction coefficient) **(Table 1)** Secchi depth readings greater than 10 m depict good water clarity (high transparency) while readings less than 5 m suggest a moderate degree of turbidity imparted by either particulate or dissolved matter (low water transparency). Water transparency at all Williston Reservoir stations in 1999 was generally low with mean Secchi values of between 3-4 m. At most stations transparency tended to increase seasonally from low Secchi values in June and July during the peak of 'freshet,' to progressively higher values through summer and into early fall. The highest Secchi reading - 7.0 m was measured in October in Finlay Reach, while the 2 lowest occurred at Forebay station in September - 1.7 m and at the Finlay Reach station in July - 1.9m. Seasonally, the Peace Reach station at Clearwater was the least turbid and Forebay station the most turbid. In 2000 there was not as much variance in Secchi depths, and mean values for the 5 stations only ranged between 3.5-5.0 m. Clearwater station in both years was the least turbid station with a average Secchi of 5 m, but Junction station, not Forebay, was the most turbid sector of the reservoir in 2000.

Highest average light extinction coefficients (greatest light extinction and shallowest compensation depth) occurred in Parsnip Reach where $k = 0.99$, followed by Finlay Reach $-k = 0.75$. Junction, Peace and Forebay stations had very similar low (least light extinction and deepest compensation depth) average k values ranging from $k = 0.69$ - 0.71. Monthly k values computed for each station are given in Appendix C.

Total Dissolved Solids (TDS) **(Table 1)** Total dissolved solids reflect the degree and characteristics of hydro-geological weathering and anthropogenic disturbance within the drainage basin. The highest average TDS values in Williston Reservoir occurred in the Finlay Reach (119 mg/m^3 in 1999, 122 in 2000), and the next highest were in the Forebay station (111 mg/m^3 in 1999, 109 in 2000). The lowest TDS values occurred in the Parsnip Reach (88 mg/m^3 in 1999, 94 in 2000). TDS values at Junction and Clearwater were between these two extremes. Trends in distribution of TDS noted in 1999 were very similar at all stations in 2000, the only exception being slightly higher TDS values in 2000 noted in Finlay and Parsnip Reaches.

Nitrogen (N) **(Table 1, Appendix C)** Of the 2 directly utilizable forms of N by phytoplankton, ammonium is the most readily assimilated. Ammonium concentrations in Williston are ephemeral and generally so low as to be undetectable by chemical measurement, hence nitrate-N (NO_3-N) becomes the most important form of dissolved N supporting algal growth in Williston Reservoir. Both total N (TN) and total dissolved N (TDN) were also measured, but these fractions include particulate (TN) and dissolved (TDN) forms of organic-N that are not readily assimilated and very slowly broken down by bacteria or algal enzymes (i.e. refractory). Nitrate concentrations in Williston averaged 57 mg/m^3 in 1999 and 62 mg/m^3 in 2000, and values were always well above detection limits at all stations *except* in the Finlay Reach, where epilimnetic concentrations declined to 13 mg/m^3 in June and to below detection levels in August, 1999, and to just above detection limits (3 mg/m^3) in August, 2000. Highest epilimnetic nitrate concentrations occurred in the Parsnip Reach, exceeding 177 mg/m^3 in June 1999 and 195 in June 2000. Nitrate values at Junction and the 2 Peace Reach stations averaged between 55-65 mg/m^3 in both years, and did not decline to values low enough to limit phytoplankton growth. TN and TDN values were consistently high and remarkably constant throughout the system in 1999, except for a moderate decline in Finlay Reach in June and August. TN and TDN were not determined in 2000 because of consistencies at all stations during the 1999 studies.

Phosphorus **(Table 1, Appendix C)** The Williston Reservoir monitor measured 2 forms of phosphorus: total phosphorus **(TP)**, which includes the particulate organic and inorganic fractions, and total dissolved phosphorus **(TDP)**, the amount passing through a membrane filter. Concentrations of TP averaged 6.2 mg/m^3 for the whole reservoir and seasonally ranged between highs of 11 mg/m^3 to lows of 2-3 mg/m^3 in 1999. In year 2000 TP was slightly higher at all stations, averaging 7.4 mg/m^3 and ranging between 6.2-9.2 mg/m^3. The only discernible spatiotemporal pattern was the elevated values in July/August, when particulate organic (phytoplankton) and inorganic particles from freshets increased concentrations. TDP values were about 30-40% lower than TP, and averaged 3.6 mg/m^3 in 1999 and 4.7 in 2000. Concentrations were highest in both years in the Parsnip Reach >5 mg/m^3 and were lowest in Finlay Reach - 3 mg/m^3 in 1999, and Peace Reach - Clearwater and Forebay in 2000 - 3.9 mg/m^3.

Table 1. Mean annual values for selected physico-chemical and biological variables from May - November 2000. (Units are *mg/m³* unless otherwise given)

Variables	Parsnip Reach		Finlay Reach		Junction Station		Peace (Clearwater)		Peace (Forebay)		Williston Reservoir Mean	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Epilimnion Ave.	15	20	30	25	20	22	30	30	40	37	28	26
Maximum Epi-Temp (C°)	19	16	17	13	15	15	13	15	15	16	16	15
Secchi depth (m)	3.2	4.1	4.3	4.0	3.4	3.5	4.0	5.0	2.8	4.1	3.5	4.1
Extinction coefficient		0.99		0.75		0.69		0.71		0.71		0.77
TDS (mg/L)	88	94	119	122	100	103	111	105	111	109	106	107
TP	6.0	7.9	6.5	9.2	6.5	7.4	6.0	6.2	6.0	6.4	6.2	7.4
NO_3	80	105	14	16	68	58	63	65	60	67	57	62
TDP	5.0	5.6	3.0	5.4	4.0	4.5	3.0	4.1	3.0	3.9	3.6	4.7
NO_3:TDP	16.0	18.7	4.7	2.9	17.0	12.9	21.0	15.8	20.0	17.1	15.7	13.5
Picoplankton (APP) No./mL		20,340		22,461		16,788		14,660		23,830		19,615
Bacteria No. $x10^3$/mL		1,230		1,450		1,196		1,144		1,154		1,234
Chlorophyll a	1.6	1.5	1.4	1.6	1.4	1.5	1.4	1.3	1.3	1.1	1.4	1.4
Phyto density (cells/mL)	4,498	4,471	5,520	5,858	5,782	3,854	3,780	3,311	4,067	5,358	4,729	4,571
Phyto BioV. (mm^3/L)	0.50	0.334	0.42	0.418	0.31	0.179	0.23	0.207	0.18	0.228	0.33	0.273
Primary Production ($mgC/m^3/hr$) ($mgC/m^3/day$)	24.5	9.8 33.9	34.5	12.4 44.5	31.0	9.3 32.9	nd	9.6 34.7	17.5	7.1 25.3	26.8	9.6 34.3
Prod/Biomass (P/B ratio)		22.6		27.8		21.9		26.7		23.0		24.3
Zooplankton (No./L)	2.6	2.3	6.1	10.3	4.1	3.9	5.1	3.4	14.6	8.7	6.5	5.7
Biomass (µg/L)	12	9	32	53	16	17	16	10	34	29	22	24

N:P ratio **(Table 1, Appendix C)** Because of large contributions of refractory organics and inorganic particulates that are included in both TN and TP measurements, a TN:TP ratio has little relevance when looking for potentially limiting nutrients to phytoplankton growth. A more meaningful assessment of potential nutrient limitation can be obtained by looking at a ratio based on dissolved nutrients that are easily assimilated by phytoplankton, namely nitrate + ammonia/dissolved phosphate (PO_4). Since ammonia (NH_3) was below detection limits at all stations and PO^4 was not measured (concentrations were below detection limits), a NO_3-N:TDP ratio was used as the best ratio to assess possible N or P limitation of phytoplankton growth in the reservoir. Values of the NO_3-N:TDP ratio averaged 15.7 in 1999 and 13.5 in 2000 for the whole system, and were lowest in the Finlay Reach - 4.7 (1999) and 2.9 (2000), and were highest - 20 in the Peace Reach in 1999 (mainly due to low TDP values) and in Parsnip Reach - 18.7 and in Forebay - 17.1 in 2000. Highest ratios occurred in May and June and lowest in August and September.

Bacteria (Figs. 5 and 6)

The abundance of free-living bacteria populations in the upper epilimnion (0-5 m) of Williston Reservoir was monitored only in 2000. Average bacteria abundance was 1.2 x 10^6/mL and their densities ranged from a high >3 x 10^6/mL in Parsnip Reach in May to a low of about 600 x 10^3/mL in Parsnip Reach in November. Apart from the exceptionally large peak in May in Parsnip Reach, bacterial densities in Williston tended to be lower in spring and early summer (May, June, July) and higher in late autumn (September, October, November) (Fig. 5). The highest fall values were found at Finlay Reach and at the Peace Reach stations, with the notable occurrence of an very large population increase > 2 x 10^6/mL in November at the Peace - Forebay station. Highest average bacteria density was in Parsnip Reach and lowest at Forebay Station with a trend toward declining bacterial density moving from west to east in the reservoir (Fig. 5).

Fig. 5. Monthly abundance of epilimnetic free-living bacteria (1-5 m) at stations in Williston, 2000.

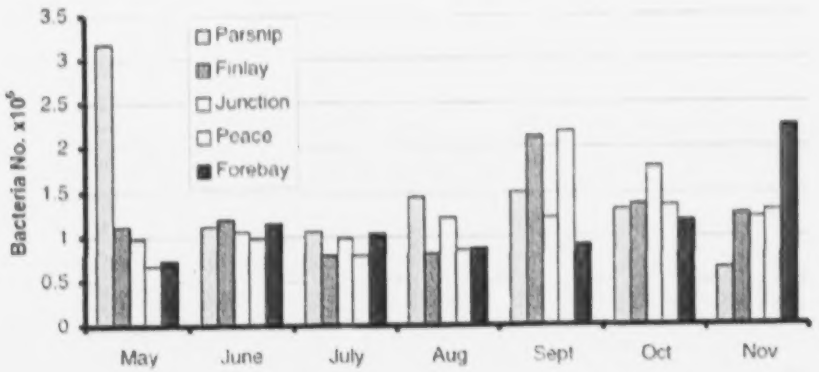
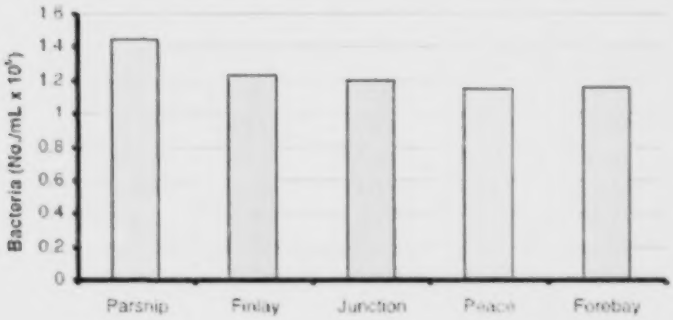


Fig. 6. Average abundance of epilimnetic free-living bacteria by station, Williston Reservoir, 2000.



Phytoplankton

Chlorophyll (biomass) **(Table 1, Appendix C)** Values of both chlorophyll and phytoplankton biovolume provide estimates of the standing stock of autotrophic phytoplankton 'biomass' in the reservoir. Chlorophyll concentrations in 2000, as in 1999, were remarkably uniform, varying from lows of <0.4 to highs of 3.7 mg/m^3 at 5 m in Finlay Reach in June. The average concentration for the reservoir in 2000 was 1.4 mg/m^3. In 1999 the highest average concentrations occurred in the Parsnip Reach - 1.6 mg./m^3, and lowest was observed at Forebay station - 1.3 mg/m^3. In 2000 the highest average station value was at Finlay Reach - 1.6 mg/m^3, and the lowest was again at Forebay station - 1.1 mg/m^3.

Species **(Appendix A)** Phytoplankton species assemblages were very similar among the 5 stations and were numerically dominated by APP, notably the small cyanobacteria - *Synechococcus* sp. and a very minute, rod-shaped *Oscillatoria* sp.. The most common diatoms found at all stations in the reservoir in both years were- *Cyclotella stelligera, Cyclotella comta, Asterionella formosa, Fragilaria crotonensis, Fragilaria* spp., *Aulicoseira distans* and *Stephanodiscus* sp. There was also a great diversity of nano-flagellates ranging in size from 2-20 µm, and the most common genera were *Chromulina, Chroomonas, Chrysochromulina, Cryptomonas, Rhodomonas,* and *Dinobryon.* The dinoflagellates *Peridinium* and *Gymnodinium* were present, but not common and they never attained large populations in the reservoir, but because of their large size they did make a significant contribution to biomass in both August and September in Parsnip Reach in 1999 and in Finlay Reach in 2000.

Vertical distribution **(Fig. 7)** Throughout much of the growing season in 2000 there was little variation in phytoplankton population density or biomass among depths sampled - 1, 3, and 5 m. In 1999 there were 2 exceptions, the first in Parsnip Reach where populations at 1 m in June and July were 2-3X higher than those at 5 m, and the second at Junction station where an APP peak occurred at 5 m in early July. In 2000 the only major difference in phytoplankton depth distribution among major groups was again a 3-5 m peak of APP at Finlay Reach station in July, otherwise populations showed a very consistent and uniform distribution within the upper epilimnion of the reservoir throughout the year at all stations.

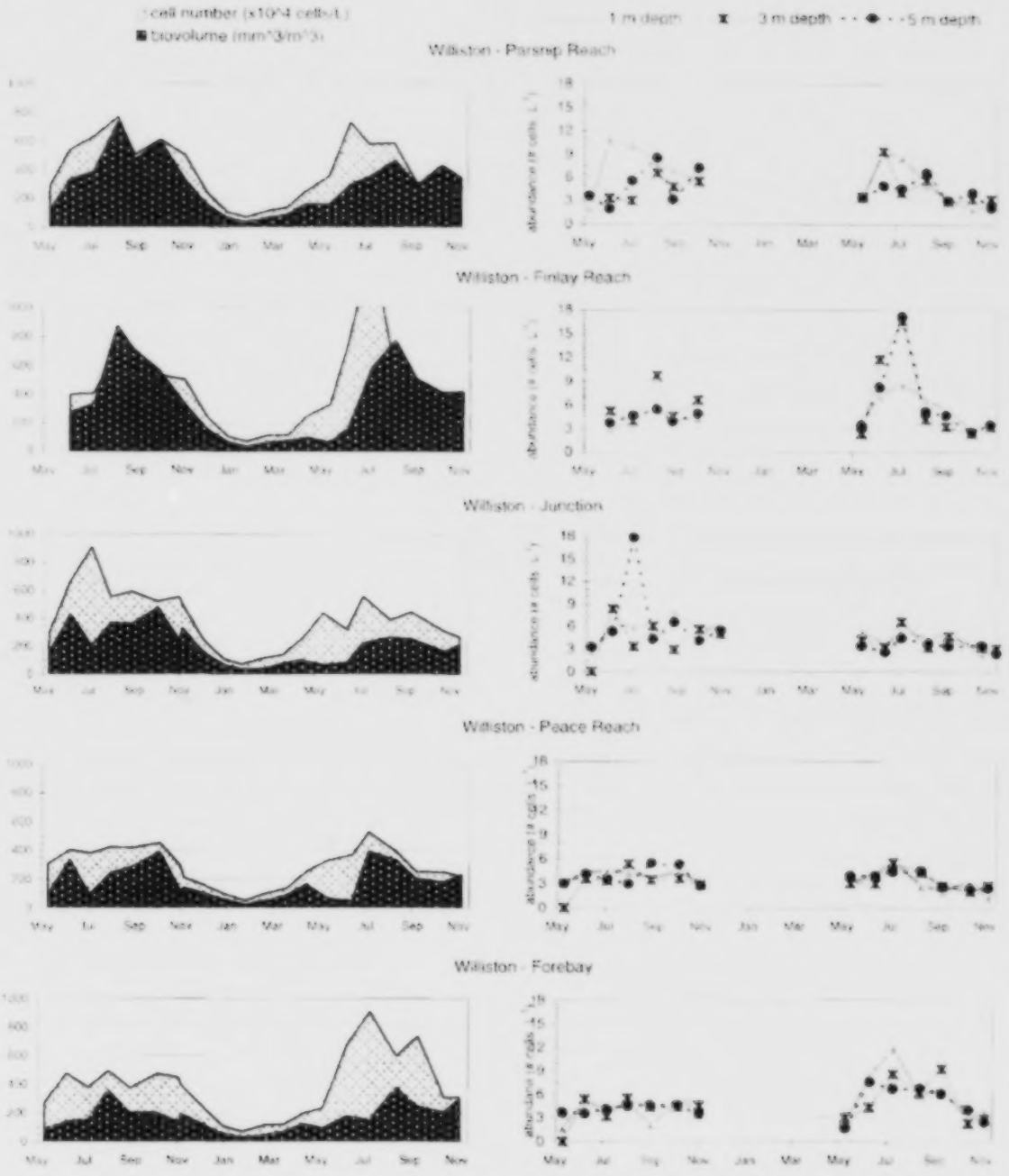


Figure 7. Seasonal (May-Nov) epilimnetic phytoplankton average abundance and biomass, and abundance at three depths in Williston Reservoir in 1999 and 2000. Note: Nov-Apr data interpolated.

Density, biovolume, and seasonal trends by group **(Figs. 7 and 8)** In 1999 average phytoplankton population densities ranged from a high of about 5,700 cells/mL at the Junction to a low of just over 3,700 cells/mL at Peace Reach - Clearwater, and averaged for the whole reservoir - 4,729 cells/mL. In 2000 densities were similar to those of 1999, but with higher densities seen in the Finlay Reach and at Forebay and lower densities at Junction and Peace Reach -Clearwater. Average cell density in 2000 for the reservoir was 4,571 cells/mL, considerably lower than in 1999. Average phytoplankton biovolume in 1999 ranged from a high at Finlay Reach of 0.50 mm^3/L to a low of 0.18 at Forebay station. The average phytoplankton biovolume for the whole reservoir was 0.33 mm^3/L in 1999 and slightly lower in 2000 - 0.27 mm^3/L.

In both 1999 and 2000 small pico-cyanobacteria (Cyanophytes) were numerically the dominant Class at all stations, with the nano-flagellates (Chryso- and Cryptophytes) the next most abundant group followed by diatoms (Bacillariophytes), dinoflagellates (Dinophytes) and green algae (Chlorophytes). There were no major peaks or blooms, and surprisingly little seasonal variation in either phytoplankton abundance or biomass in Williston in both 1999 and 2000. Highest average densities occurred at Finlay Reach and Junction station in 1999, and at Finlay Reach and Forebay station in 2000. Lowest phytoplankton population densities occurred in May in both years and peaks in total numbers and biomass occurred at most all stations in July/August, largely attributable to increases of pico-cyanobacteria, diatoms and nano-flagellates. Seasonally, among all stations, the Finlay Reach had the highest density and biomass of diatoms and lowest of picoplankton, while Parsnip Reach had the highest density and biomass of nano-flagellates in 2000, but in 1999 the 2nd lowest. Phytoplankton abundance and biomass in the Peace Reach - Clearwater were the lowest in the reservoir in both years. The characteristic bi-modal diatom peak that occurs in large, dimictic lakes after spring and fall mixing periods was not seen in Williston Reservoir, rather only a single, somewhat protracted, mid-summer diatom, nano-flagellate and dinoflagellates increase, most apparent at Finlay Reach station. In both years there was a trend toward diminishing phytoplankton biomass (biovolume) from west reaches to the eastern Peace Reach stations, with Finlay and Parsnip reaches showing considerably higher biomass than either Peace - Clearwater or Forebay stations, and with Junction station values lying between these two extremes.

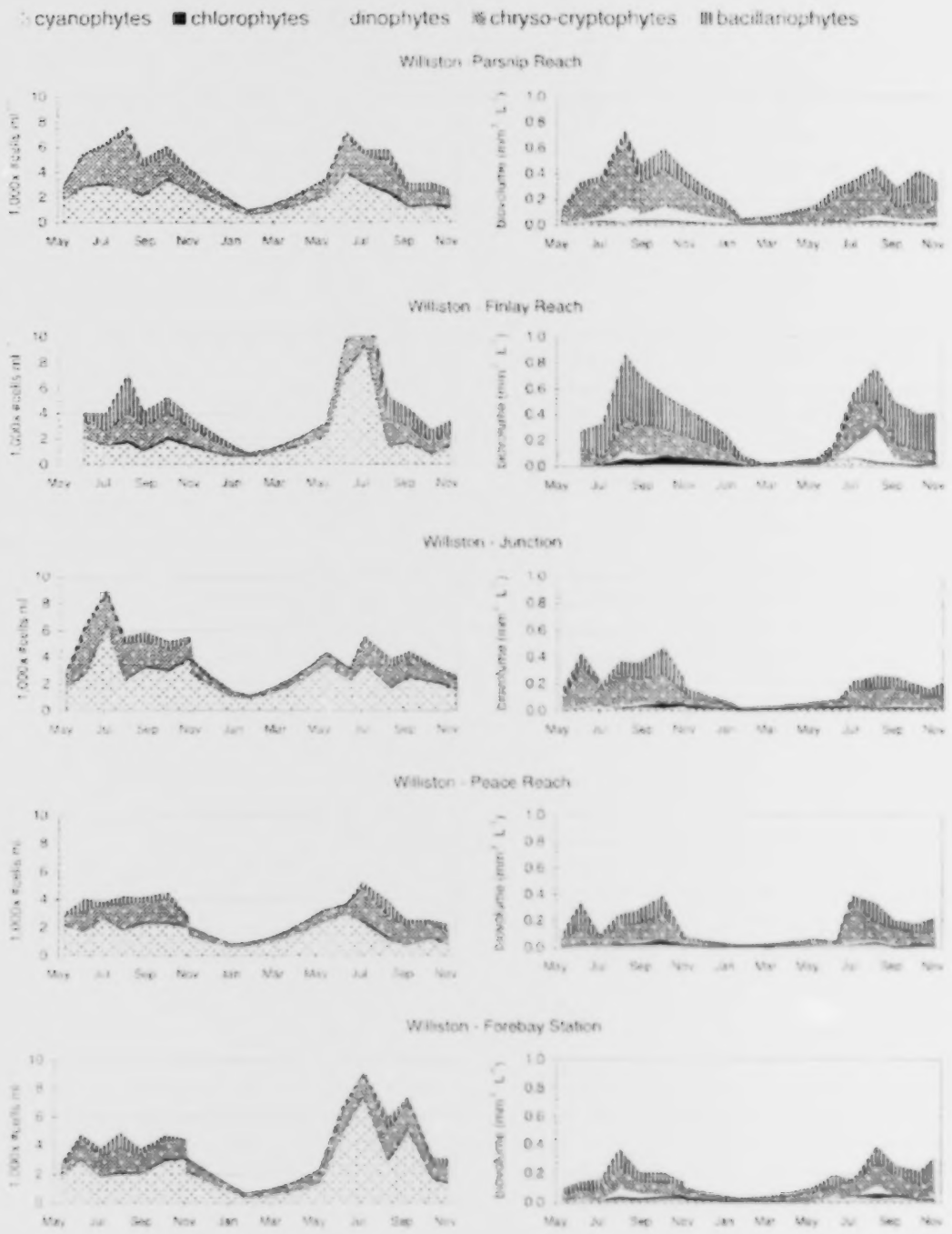
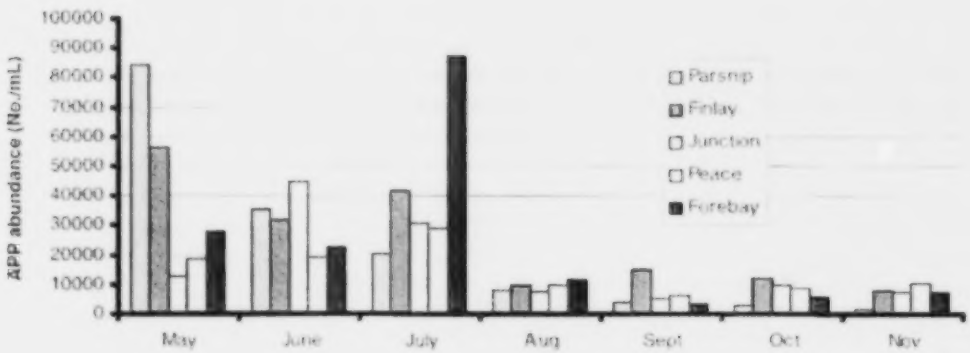


Figure 8. Seasonal (May-Nov.) abundance and biomass of the major phytoplankton classes in Williston Reservoir in 1999 and 2000. Note: Nov-Apr data interpolated.

Autotrophic picoplankton (APP).

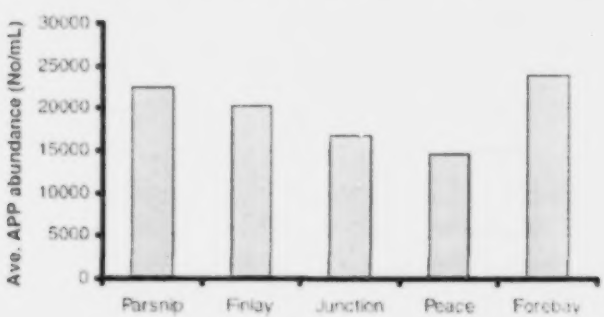
Abundance in 2000 (Fig. 9 and 10) Autotrophic (photosynthetic) picoplankton APP are the most abundant phytoplankters in Williston Reservoir, and though of small size (1.5-2.0 µm) their rapid growth rate is capable of sustaining high organic C production that supports microbial food webs. In Williston in 2000 APP population abundance ranged from peaks of >80,000 cells/mL in May in Parsnip and July at Forebay to lows of < 10,000 cells/mL at all stations in autumn. Their average density in the reservoir was 19,615 cells/mL (N=35). The largest populations of APP at all stations occurred in spring months (May, June, and July) and at all stations, APP populations rapidly declined in August and remained low throughout the rest of season to early November.

Fig. 9. Monthly average abundance of APP (1-5 m) at Williston Reservoir stations, 2000.



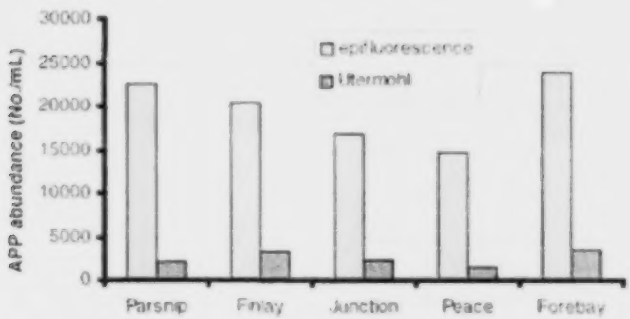
As was noted with bacterial densities, there was a trend toward diminishing APP seasonal average abundance moving west to east in the reservoir with the exception of Forebay station where average densities tended to be higher (Fig. 10).

Fig. 10. Average abundance of APP by station, Williston Reservoir, 2000.



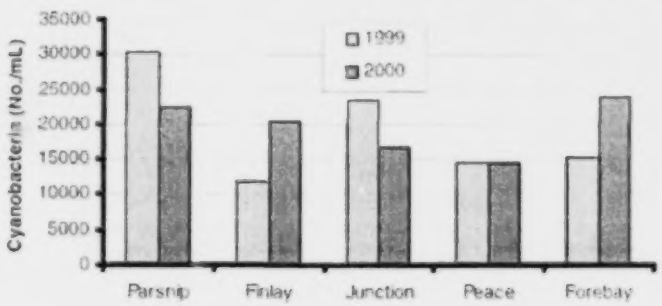
Method comparison **(Fig. 11)** In 1999 APP were counted only by the Utermohl (1958) settling chamber method that underestimates total population size owing to slow APP settling rates in counting chambers. However in 2000 both the Utermohl and the more accurate epifluorescence method were used, enabling a comparison of APP abundance by 2 enumeration methods. Utermohl counts underestimated APP abundance by a factor of 8. 1X in Williston (range - 11.7-6.2X). The average Utermohl APP count in 2000 was 2,592 cells/mL, and with correction factor (8. 1X) applied provides a population estimate of 20,995 cells/mL, very close to the average epifluorescence APP count for Williston of 19,615 cells/mL in year 2000.

Fig. 11. Average abundance of APP by station computed by two methods of enumeration in Williston Reservoir, 2000.



APP populations in 1999 **(Fig. 12)** By applying the APP correction factor to Utermohl counts from each station enabled estimation of an average APP population abundance by station in Williston in 1999 that can be compared to APP counts by epifluorescence in 2000. In both years there were large APP populations in Parsnip Reach and low densities at Peace Reach - Clearwater. Forebay and Finlay station populations were low in 1999 but higher in 2000. Another difference between years was the absence in 1999 of a trend toward diminishing population size from west to east in the reservoir as was apparent in 2000.

Fig. 12. Average abundance of APP by station in Williston Reservoir in 1999 by corrected Utermohl counts, and in 2000 by epifluorescence counts.

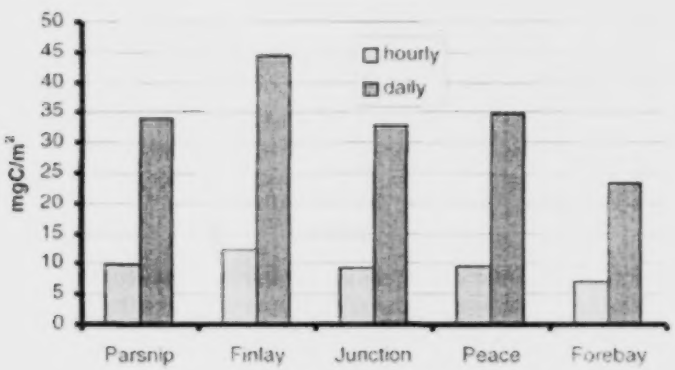


Primary Production.

Spatial and vertical trends -1999 Measurements of photosynthetic rates (PR) were done only in July and September 1999, but there were some interesting trends noted in these preliminary primary production runs. The first was that the highest average PR rates occurred on both dates within the Finlay Reach (34.5 $mgC/m^2/hr$) and the lowest on both dates at the Forebay station - Peace Reach (17.5 $mgC/m^2/hr$). After Finlay, the next highest rates were measured at the Junction station (31.0 $mgC/m^2/hr$), which was only marginally higher than values measured in Parsnip Reach (24.5 $mgC/m^2/hr$). The highest PR rates occurred at all stations in July at a depth of 1 m but by September the highest PR rates were noted at 3 m at all stations.

Spatial, seasonal and vertical trends -2000 **(Figs. 13 - 16)** Average hourly values for the Williston Reservoir in 2000 were 9.6 $mgC/m^2/hr$ and 34.3 $mgC/m^2/day$, and as noted in 1999 highest values were in Finlay Reach and the lowest at Forebay station (Fig. 13). Junction, Parsnip and Peace stations had similar averages of about 10 $mgC/m^2/hr$ and >30 $mgC/ m^2/day$. Highest monthly production values were in August at all stations and the lowest were in spring, May and June. Production declined abruptly in September at all stations but increased again to moderately high levels in October and November during the reservoir's autumn transition (deep mixing) period.

Fig. 13. Average primary production rates by station in Williston Reservoir, 2000 (N=7).



May, June and July, 2000 are best characterized as low production months with similar daily and hourly values that ranged between 10-20 $mgC/m^2/day$. In August PR increased about 4-5-fold over spring values (Fig. 14), with the largest increases in Parsnip Reach (9X) and at Forebay (8X) stations (Fig. 15). The striking August PR peaks were coincident with peaks of phytoplankton biomass and density at most all stations. In October and November production values increased again to moderately high levels with values measured in Finlay Reach the highest among stations during both months (Fig. 15).

Fig. 14. Average monthly primary production in Williston Reservoir, 2000.

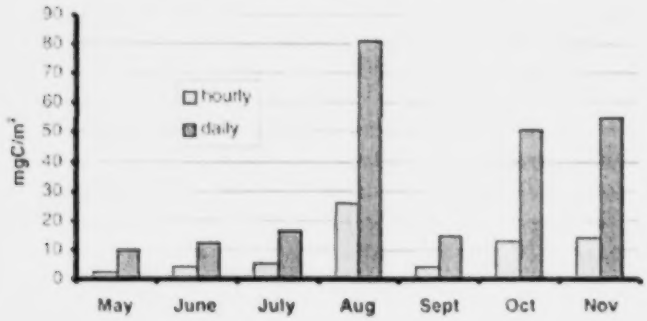
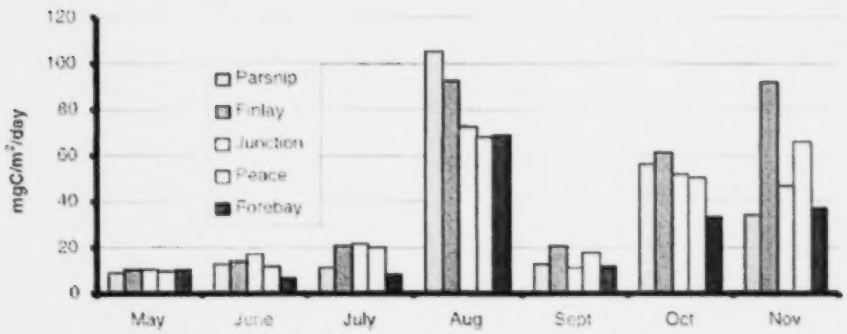
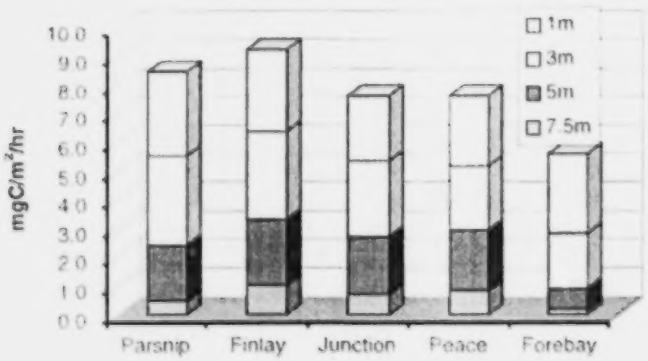


Fig. 15. Average daily primary production by month and station in Williston Reservoir, 2000.



The depth distribution of primary production rates mirrored the vertical distribution of phytoplankton, showing little spatiotemporal variation. The highest rates of carbon production were in the surface waters - 1 and 3 m depths. Diminishing values occurred with increasing depth, and lowest values were always at 7.5 m (Fig. 16). There was no strong indication of any major light inhibition of growth in near-surface waters, and maximum values most often occurred at either 1 or 3 m depth, depending on month and ambient light conditions during the experiment.

Fig.16. Seasonal average depth distribution of primary production in Williston Reservoir, 2000.



Size fractionated production - 2000 **(Fig. 17a, b).** In 1999 no size-fractionated production experiments were preformed, but in 2000 primary production measurements during the months of August and September were fractionated into 3 phytoplankton size categories: **pico-** <2 µm, **nano-** 2-20 µm, and **micro-** >20 µm to determine contribution by size to total carbon (C) production. Pico- and nano-plankton contributed > 80% to the total C production at all stations in both months, the only exception being in Finlay Reach in September, when the presence of large diatoms increased the contribution of micro-plankton to about 30% of the total. The most productive fraction was clearly pico-plankton (i.e. *Synechococcus* sp.), contributing about 45-55% to total C production. Nano-plankton, which included most of the Chryso and Crypto-flagellates and some small green algae, were the next most productive fraction contributing around 25-35% to the total C, and the least productive was micro-plankton consisting mostly of diatoms and dinoflagellates contributing <10%.

Fig.17a. Phytoplankton production by size class in Williston Reservoir, August 2000.

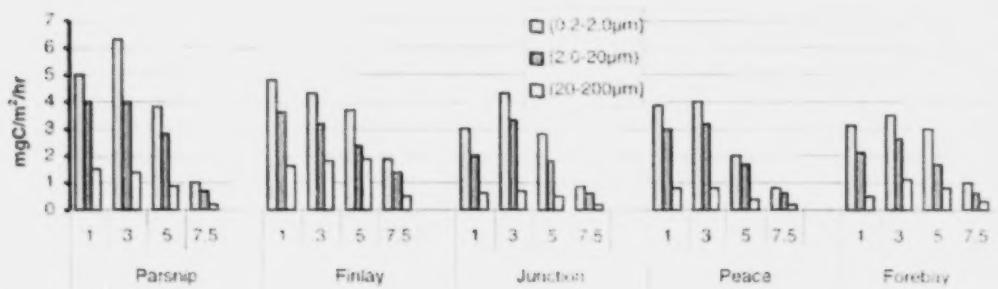
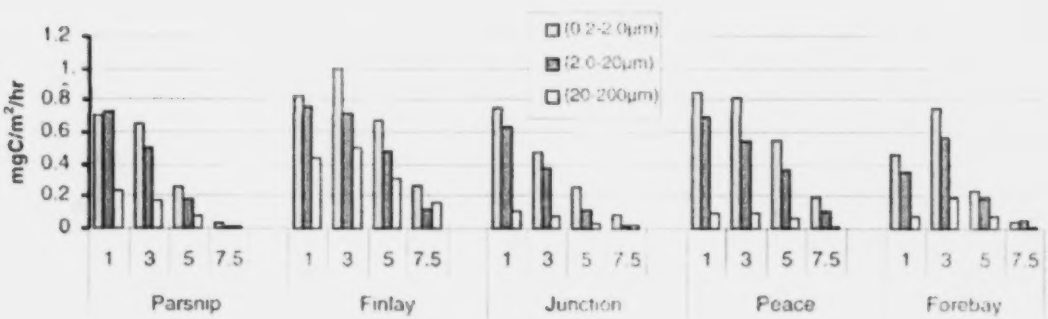


Fig. 17b. Phytoplankton production by size class in Williston Reservoir, September 2000.



Production to biomass ratio (P/B) **(Table 1).** The P/B ratio, sometimes called the 'assimilation efficiency' provides a snapshot of the rate of C production per unit of phytoplankton biomass (chlorophyll), i.e. how many mg C are produced by a mg of chlorophyll per unit time (hrs, days). By station the most efficient hourly production in Williston Reservoir was at Finlay Reach - 1.03 P/B and the next highest was found at Peace-Clearwater - 0.98 P/B. Forebay and Parsnip had similar P/B ratios - 0.86 and 0.87, and the least efficient was at Junction station - 0.83 P/B. The average P/B for Williston Reservoir was 0.92 P/B, very similar to fast-flushing BC coastal systems.

Zooplankton.

Abundance and Biomass **(Figs. 18, 19, Tables 2, 3, and Appendix A)** Zooplankton species identified are listed in Appendix A. Like phytoplankton, the pelagic zooplankton populations in Williston Reservoir show a diverse species assemblage, with relatively consistent population sizes between years 1999 and 2000. Seasonal (June to October) abundance decreased slightly, from 6.5 in 1999 to 5.1/L in 2000, while biomass slightly increased from 22 to 23.5 µg/L, respectively. There was a wide range in values between sites, with density at most sites remaining relatively constant between years. The Junction and Parsnip reaches had the lowest population densities that ranged from 3-4/L and a biomass from 9-16 µg/L. Density was slightly higher 3-5/L in the Peach Reach where both density and biomass decreased slightly in 2000. The largest changes were recorded at the Forebay station and in the Finlay Reach, where populations were also the largest. Seasonal density decreased at the Dam site from 15/L in 1999 to 8.7/L in 2000, and due to a decline in copepodite biomass also decreased. Populations increased in the Finlay Reach from 6/L in 1999 to 10/L in 2000, the highest average density recorded at any site in 2000. However, the increase may in part be due to sampling that began a month earlier at this site in 1999 than in 2000.

Seasonally, zooplankton density peaked concurrent with phytoplankton peaks in July/August at values of 4-10/L at most stations. The exceptions were the Forebay site where density peaked at 25/L in 1999 and 16/L in 2000, and at the Finlay Reach site where density peaked earlier in June, at 17/L in 2000 (Fig. 18). The average reservoir population composition was similar between years, with 90% copepods and 10% cladocerans (by density), but there was a wide range between sites. The Finlay Reach contained the largest percent of cladocerans at 23%, and Peace Reach the lowest at 2%.

Fifteen species of macrozooplankton were identified in the samples, with cosmopolitan species such as *Leptodiaptomus ashlandi, Diacyclops bicuspidatus thomasi,* and *Daphnia galeata mendotae* among the more numerous. Of note, there were three species of *Daphnia* and four species of *Leptodiaptomus* identified, along with the rarely seen *Heterocope septentrionalis.* Five species of rotifers *(Keratella quadrata, K. cochlearis, Polyarthra* sp., *Asplanchna* sp. and *Kellicottia* sp.) were also identified in the samples but are not addressed in this report. The large mesh size of the net (80 µm) would not capture most of the rotifers, and therefore any density values given would largely underestimate the true population size.

Fig. 18. Density of dominant cladocerans *(Daphnia* spp.) and copepods *(Diacyclops* spp. & *Leptodiaptomus* spp.) zooplankton in Williston Reservoir 1999 and 2000.

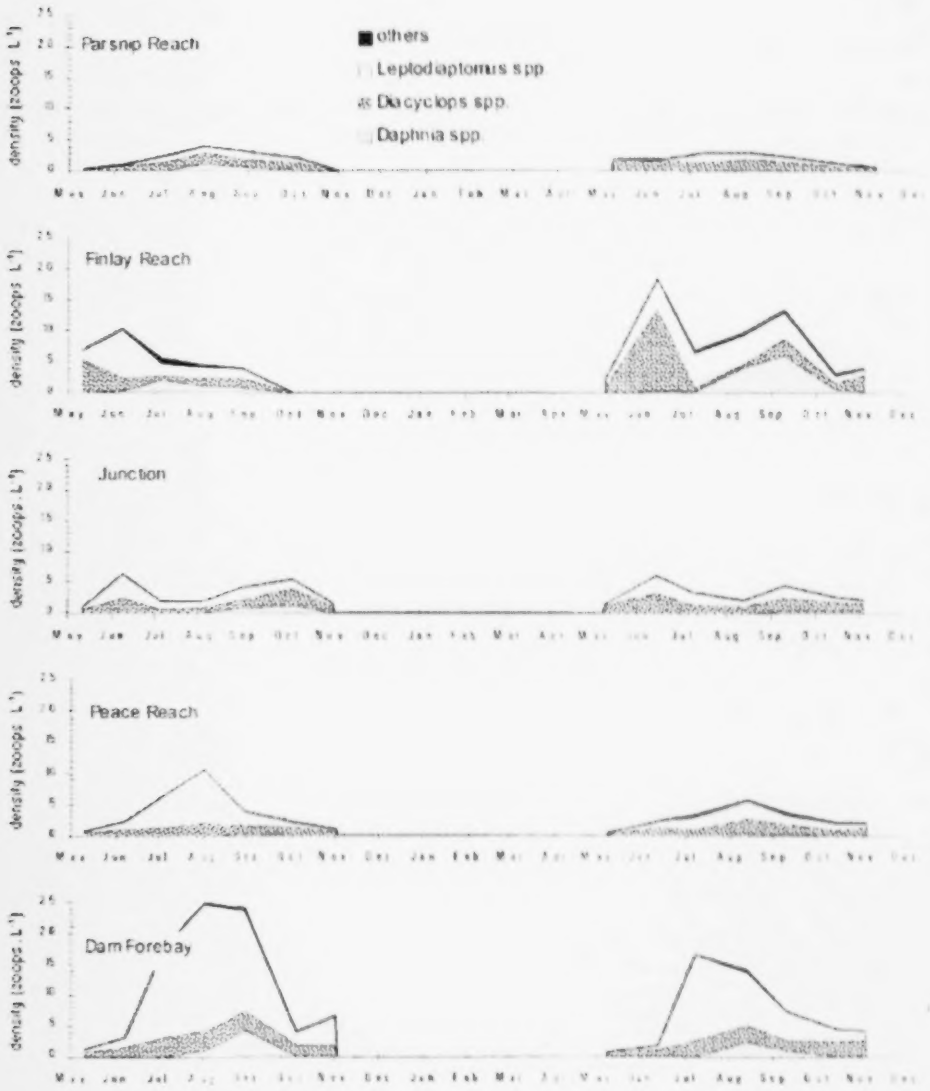


Fig. 19. Biomass of dominant cladocerans *(Daphnia* spp.) and copepods *(Diacyclops* spp. & *Leptodiaptomus* spp.) zooplankton in Williston Reservoir, 1999 and 2000.

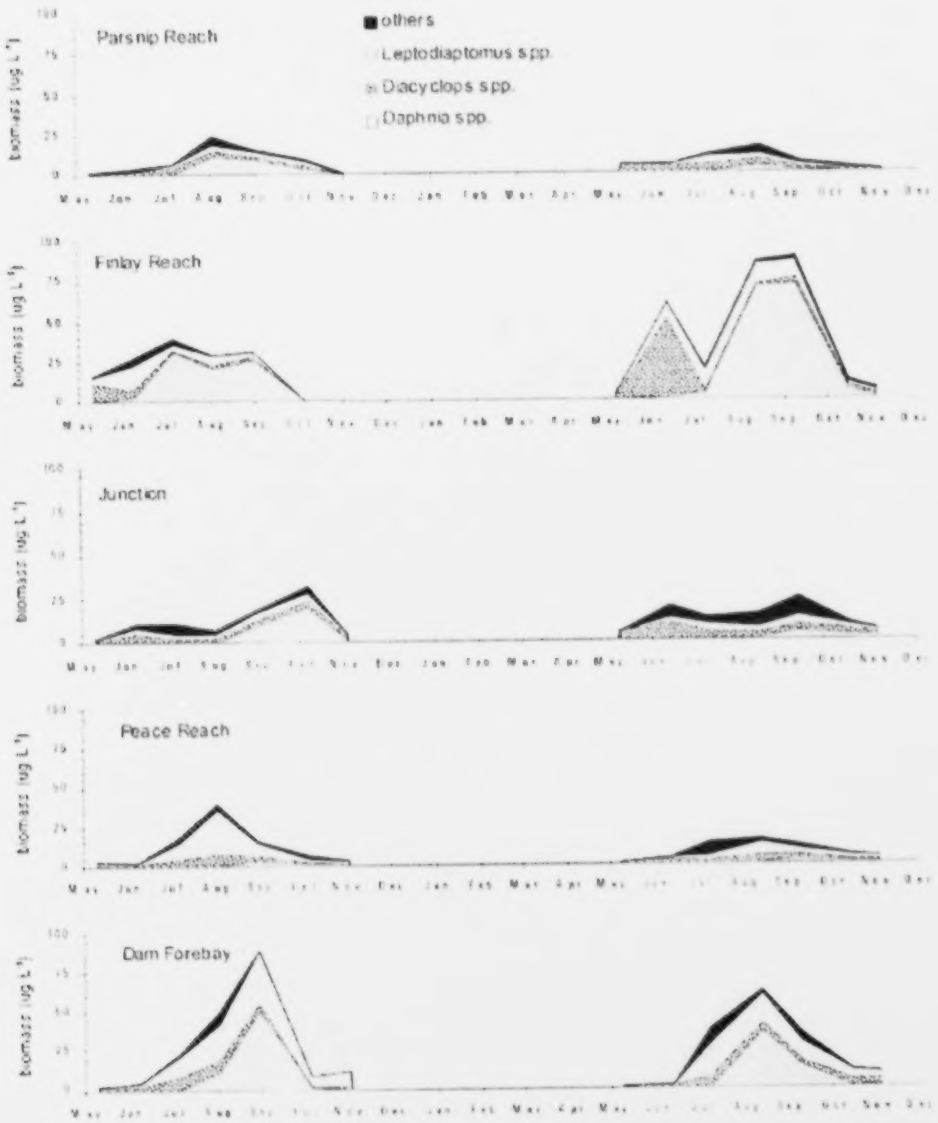


Table 2. Seasonal (June-Oct.) macrozooplankton genera captured and average abundance (No./L) at the different sample stations in Williston Reservoir, 1999-2000.

species	Parsnip		Finlay		Junction		Peace		Forebay		average	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Cladocera												
Eubosmina longispina	0.01	0.01	0.26	0.08	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	0.06	0.02
Diaphanosoma sp.[a]	0.01	0.02	<0.01	0.06	<0.01	0.01	<0.01	0.01	0.02	0.02	0.01	0.02
Leptodora kindtii	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Daphnia spp.	0.42	0.08	1.09	2.26	0.46	0.16	0.07	0.06	1.04	0.63	0.61	0.64
Holopedium gibberum	0.01	0.01	<0.01	<0.01	0.01	0.02	0.01	0.01	<0.01	0.02	0.01	0.01
Total Cladocera	0.44	0.11	1.34	2.40	0.46	0.18	0.07	0.08	1.06	0.65	0.68	0.68
Copepoda												
Diacyclops spp.	1.33	1.32	1.24	3.54	1.62	1.91	1.49	1.46	2.37	2.00	1.61	2.04
Heterocope septentrionalis	<0.01	0.01	<0.01	<0.01	0.03	0.01	0.02	0.02	<0.01	<0.01	0.02	0.01
Epischura nevadensis	0.01	0.01	0.01	0.01	<0.01	0.12	0.01	<0.01	0.01	0.10	0.01	0.05
Leptodiaptomus spp.	0.86	0.86	3.5	4.3	2.0	1.7	3.5	1.9	1.11	6.0	4.2	3.0
Total Copepoda	2.2	2.2	4.7	7.9	3.6	3.8	5.1	3.3	13.5	8.1	5.82	5.1
Total zooplankton	2.6	2.3	6.1	10.3	4.1	3.9	5.1	3.4	14.6	8.7	6.50	5.7

[a] *Diaphanosoma brachyurum*

Copepods were numerically the dominant macrozooplankton group in Williston Reservoir, averaging 90% of total zooplankton density and 53% of biomass (Table 3). The largest copepod populations in each year were found at the Forebay site, averaging 13.5/L and 8.1/L in 1999 and 2000, respectively, with densities ranging from 2-8/L at the other sites. The Forebay had the largest proportion of copepodites, with the density of adult copepods similar to other sites. The drop in density at Forebay site was due to a decrease in seasonal copepodite density, which dropped from 10/L in 1999 to 5/L in 2000. Copepod densities peaked in August at most stations, except at Junction and Finlay Reach sites where densities peaked in June. In the Finlay Reach, copepod density peaked at 18/L on the June 7th sampling in 2000, while a peak of only 11/L was recorded in early-June, 1999, however, sampling started later in 1999 and the peak copepod density may have been missed. *Diaptomus* was the dominant copepod, which is typical of most water bodies (Wilson and Yeatman 1956), and with an average density of 3 to 4/L was the most numerous genus of zooplankton captured, especially at the Forebay and Finlay Reach stations. Four species of *Leptodiaptomus* were found with *L. pribilofensis* and *L. ashlandi* the most numerous, accounting for the majority of *Leptodiaptomus* density. The other *Leptodiaptomus* species were *L. sicilis* and *L. denticornis,* with densities averaging <0.01/L.

Diacyclops was the only cyclopoid copepod identified and was the second most numerous copepod and zooplankton genus captured, with an average density of 1.8/L in both years. Of the two *Diacyclops* species captured, *D. scutifer* was the more numerous with populations peaking at 0.1-3/L usually in late-July, and *D. bicuspidatus* peaked slightly later in the summer at densities no greater than 0.25/L. A peak *D. scutifer* adult density of 3/L was recorded at the Finlay Reach site on the June 7th sampling trip, while a peak of only 0.6/L was recorded in early-June of 1999, however, as stated earlier sampling started later in 1999 when the peak *D. scutifer* density may have been missed. Several *Heterocope septentrionalis* were captured in mid-to-late summer at each station (densities <0.003/L). *Heterocope* are large individuals and rarely captured, especially

in pelagic tows, and were probably captured near the bottom of the 30 m tows used in this project (D. Dolecki, UBC, Dept, of Zoology, personal communication.).

Table 3. Seasonal (June-Oct.) macrozooplankton genera captured and average biomass (µg/L) at the different sample stations in Williston Reservoir, 1999-2000.

species	Parsnip		Finlay		Junction		Peace		Forebay		average	
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Cladocera												
Eubosmina longispina	0.04	0.04	0.82	0.42	0.01	0.03	0.01	<0.01	<0.01	0.05	0.18	0.11
Diaphanosoma sp.[a]	<0.01	0.14	<0.01	0.42	<0.01	0.06	<0.01	0.05	0.15	0.05	0.03	0.15
Leptodora kindtii	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Daphnia spp.	6.0	2.0	21.0	30.8	7.7	5.5	1.9	2.3	13.4	13.4	10.0	10.8
Holopedium gibberum	1.1	0.72	1.0	<0.01	1.7	3.7	1.0	1.4	1.2	3.6	1.2	1.9
Total Cladocera	6.1	2.2	21.8	31.6	7.7	5.5	1.9	2.3	13.5	13.4	10.2	11.0
Copepoda												
Diacyclops spp.	2.9	3.5	2.6	11.6	3.1	5.2	3.4	2.9	4.6	4.0	3.3	5.4
Heterocope septentrionalis	0.08	0.85	0.01	<0.01	1.05	0.68	1.06	0.95	0.06	0.05	0.45	0.50
Epischura nevadensis	0.11	0.15	0.10	0.6	0.06	2.3	0.12	0.05	0.10	1.3	0.10	0.78
Leptodiaptomus spp.	2.5	2.5	7.0	9.8	3.7	4.1	9.7	3.8	16.1	11.7	7.8	6.4
Total Copepoda	5.6	6.7	9.7	21.4	7.9	11.0	14.8	7.4	20.8	15.7	11.7	12.5
Total zooplankton	12	9	32	53	16	17	16	10	34	29	22	24

[a] *Diaphanosoma brachyurum*

Cladocerans were occasionally captured in May (when sampling began) and in June, but significant populations did not develop until July or August (Fig. 18). Peak densities were generally 1-4/L (or 20-40% of the total density), with the highest seasonal densities at the Finlay Reach site (Table 2), including the highest single cladoceran density of 6.5/L recorded in September 2000. Cladoceran densities of <0.25/L at the Peace Reach site were very low compared to the others stations. Despite their low overall abundance compared to copepods, cladoceran biomass generally peaked at 15-20 µg/L, or approx. 65% of total biomass (Fig. 19), with an overall average of 41% of the June to October biomass. As with density, there was some noteworthy variation in biomass between sites. Cladoceran biomass was very low at the Peace Reach (average 1.9 µg/L), and peaked at 75 µg/L in the Finlay Reach with the above mentioned September 2 density peak.

Five genera of cladocerans were identified in the samples (Table 3). *Daphnia* were the dominant cladoceran genera, accounting for approximately 90% of cladoceran density (and 70% of biomass), except in Finlay Reach where the largest *Eubosmina* populations were found, peaking as high as 1/L, or 20% of cladoceran densities (Fig. 1[illegible]). Three species *of Daphnia* were found, with *D. galeata mendotae* the dominant, numerically accounting for 88% of the *Daphnia* and 82% of the cladoceran density, with *D. pulex* and *D. longiremis* densities averaging about the same at 0.35/L (Fig. 18). The other cladoceran species had average densities <0.05/L, ranging from 1-5% of total cladoceran densities.

PR Model - rearing capacity.

Using the year 2000 average photosynthetic rate (PR) values for Williston it was possible to use the PR model to provide a first estimate of the reservoir's potential rearing capacity for planktivorous fish, most notably the resident kokanee (Table 4). The PR model was developed using data from anadromous sockeye stocks and juvenile growth/survival estimates from a wide variety of BC and Alaskan nursery lakes (Shortreed et al. 2000). Nonetheless, with proper adjustments for kokanee size/fecundity differences, the PR model predictions of juvenile rearing capacity based on total annual C production can be a useful guide to better understanding Williston's productive (forage base) potential.

Table 4. PR Model Predictions for Williston Reservoir, 2000.

Mean smolt weight 4.0 g					PR model predictions		
	Lake	Mean PR (mgC m^2)		Annual PR	Optimum	Maximum smolts	
Reach	area (km)	Hourly	Daily	(tC)	Escapement	Biomass (kg)	number
Parsnip Reach	720.0	10	34	4,445	8.31×10^5	2.07×10^5	5.17×10^7
Finlay Reach	709.0	12	45	5,743	1.07×10^6	2.67×10^5	6.68×10^7
Peace Reach	350.0	9	31	1,953	3.65×10^5	9.08×10^4	2.27×10^7
Williston Reservoir	1779.0	10	34	10,984	2.05×10^6	5.11×10^5	1.28×10^8

PR model - uses Annual PR (tonnes C/lake or basin)
Max. smolt biomass. (kg) = 46.5*PR
Max. smolt number = Max. biomass/mean wt.

The greatest rearing potentials are in the Finlay Reach with an estimated total production of 5,700+ t C (82 kgC/ha) followed by Parsnip Reach with 4,445 t C (62 kgC/ha) and the lowest was the Peace Reach 1,953 t C (56 kgC/ha). The PR model estimates that the productive capacity of Williston Reservoir for 2000 was 11,000 t C that is equivalent to 63 kg C/ha/yr. If Williston were an anadromous sockeye salmon nursery lake it could optimally produce 1.3×10^8 4 g smolts at current levels of autochthonous carbon production and could support an escapement of about 2 million adult sockeye into the system, assuming no spawning ground limitations exist (Shortreed et al. 2000). To place in perspective the rearing capacity of Williston, consider PR estimates for Shuswap Lake in the Fraser River basin and Babine Lake in the Skeena River basin. Because it is a much more productive system, Shuswap produces about the same annual PR (t C) as Williston but has only $1/6^{th}$ the area. Babine Lake is larger than Shuswap, and just over $1/3^{rd}$ the area of Williston. Babine Lake produces more C (12,300 t C/yr) than Williston, and the PR model predicts an optimum adult escapement of 2.3 million adults for Babine Lake (Shortreed et al. 2000).

DISCUSSION

General.

Overview. Williston Reservoir by the nature of its inception some 30 years ago by impoundment of 3 major river systems (Peace, Finlay and Parsnip rivers), is a complex and very large **'T'** shaped reservoir system. The reservoir has 2 major western basins (Finlay and Parsnip reaches) in a north/south alignment that converge at the old Parsnip/Finlay river junction and within the old Peace River canyon create a deep 3rd basin - the Peace Reach. In a recent summary report, Stockner (1998, BC Hydro, unpublished) considered the zone of convergence of Finlay and Parsnip reaches at Junction to be the major zone of ***'mixing'*** for north and south moving Parsnip and Finlay basin inflow waters. Stockner considered the narrower, deeper, Peace Reach to be the reservoir's zone of ***'integration'***, where chemical and biological features of the larger western basins are integrated by deep mixing, creating a third reach that has the potential to show subtle differences in biological and physico-chemical properties from either of the parent systems.

The discussion to follow will first focus on each of the major western basins plus Junction, then move to Peace Reach - Clearwater and conclude with Forebay station. Each will be discussed separately, presenting the major limnological features and causes for suggested differences, with an emphasis on recent results from the more intensive 2000 monitor. It is important for the reader to keep in mind that Williston Reservoir is an immense ecosystem with great geographic, geologic, and physico-chemical complexity, and with only 5 stations and two seasons to monitor conditions within the reservoir we cannot pretend to fully understand the dynamics of the system. But it is our hope that what data we have will provide a more balanced picture of the current structure and productivity of biotic communities during the 'bust' phase of Williston's ageing process, 30+ years after impoundment. Previous studies from the 1970s and early 80s had provided a glimpse at the reservoir's biotic communities during the more productive 'boom' phase of its ontogeny. Because we chose to do process research in 2000 (^{14}C production) we can for the first time provide resource managers with a better understanding of system function, and present a more scientifically based estimate of system productive potentials useful for decision making by future fish ecologists and managers.

Parsnip Reach. The Parsnip Reach is the most southerly and largest in area of the reservoir's 3 basins, and throughout the growing season exhibits the shallowest average epilimnetic depth (15-20 m), highest maximum temperatures, and low water transparency (high turbidity). The addition to the basin of high N and organic C effluents discharged at the town of Mackenzie from municipal sewage and pulp mill treatment plants through the winter months undoubtedly contribute to the very high spring values of dissolved nitrate-N and provide additional DOC required to sustain a population of free-living bacteria $>3x10^6$/mL in May. The Reach receives water input mainly from the Parsnip and Pack river drainages from the south and west of the basin, and these rivers input the lowest alkalinity (TDS), but also the highest nitrogen (NO_3-

N) and TDP loadings of all major Williston basins. With a NO_3:TDP ratio of 16-18, nutrients here remain well above detection levels throughout the summer, and phytoplankton populations and their photosynthetic rates are likely not to be limited by nutrients, but rather by light, i.e. moderately high turbidity levels in surface waters throughout the growing season. In the overall ranking by station of production potentials using 10 'key' variables (Table 5), Parsnip Reach station ranked 3rd in both years. In terms of primary production it was 3rd highest and for phytoplankton biomass 1st in 1999 and 2nd in 2000. Parsnip Reach had the least zooplankton biomass and abundance in both years. Fisheries reports are scarce and most were completed during the 'boom' period of Williston's production cycle, but recent anecdotal accounts from gillnetting and hydroacoustic work suggest it may be one of the least productive basins for fish (B. Blackman, BC Hydro; D. Sebastian, MOF unpublished data), which is opposite to the earlier finding which commented on high fish populations in Parsnip Reach (Barrett and Halsey 1985).

Finlay Reach. The Finlay Reach or north basin is the 2nd largest of Williston's major basins, and receives the greatest volume of inflow water, >2-fold higher than average inflow to the Parsnip Reach. This reach is the least turbid and most alkaline. It is quite windy and has a deeper average epilimnetic depth (30 m), indicating higher wind velocities of greater fetch in this basin than in Parsnip Reach, where epilimnetic depths are shallower. The maximum epilimnetic temperature was 17° C in 1999, slightly cooler than in Parsnip, but in 2000 it was only 13.2° C, the coldest in Williston Reservoir. One of the most striking features of Finlay Reach is the low quantity of nitrate-N, just above detection limits in June and depleted from the epilimnion in August, 1999, and just above detection (0.003 mg/m^3) in 2000. Values of TDP are also low and with a NO_3:TDP ratio of 4.7 in 1999 and 2.9 in 2000, were the lowest seen in the Williston system, indicating a potential for N limitation of phytoplankton growth and primary production during mid-summer growth periods. Finlay Reach is clearly the most productive sector of the reservoir. It ranked 1st or 2nd in all key production variables, supported the highest bacterial density, ranked 2nd highest for APP abundance, was 1st for phyto- and zooplankton abundance and biomass, and had the highest rates of primary production and production efficiency (P/B). It is quite likely that phytoplankton production in Finlay is co-limited by both N in August and by low average light conditions (2nd lowest Secchi depth). The highest pelagic fish densities in September 2000 also occurred in Finlay Reach, information that supports its ranking as the most productive sub-basin of the reservoir (D. Sebastian, MOF, Victoria, personal communication).

Table 5. Ranking of salient variables by basin for assessment of pelagic ecosystem productive capacity in Williston Reservoir in 1999 (brackets) and 2000.

Variables	Parsnip Reach	Finlay Reach	Junction Station	Peace (Clearwater)	Peace (Forebay)
TP	2	1	3	5	4
	(2)	(1)	(1)	(2)	(2)
APP No./mL	3	2	4	5	1
Bacteria No. $x10^3$/mL	3	1	2	5	4
Chlorophyll a	2	1	2	3	4
	(2)	(1)	(2)	(2)	(3)
Phyto density (cells/mL)	3	1	4	5	2
	(3)	(2)	(1)	(5)	(4)
Phyto BioV. (mm^3/L)	2	1	4	5	3
	(1)	(2)	(3)	(4)	(5)
Primary Production (mgC/m^2/day)	3	1	4	2	5
	(3)	(1)	(2)		(4)
Prod/Biomass (P/B ratio)	3	1	5	2	4
	(3)	(1)	(2)		(4)
Zooplankton (No./L)	5	1	3	4	2
	(5)	(2)	(3)	(4)	(1)
Zooplankton Biomass (µg/L)	5	1	3	4	2
	(4)	(2)	(3)	(3)	(1)
Fish[1]	3	1	2	2	2
Average Rank	3.2	1.1	3.4	3.7	2.9
	(2.8)	(1.5)	(2.1)	(2.9)	(3.0)
Final Rank	**3**	**1**	**4**	**5**	**2**
	(3)	**(1)**	**(2)**	**(4)**	**(5)**

From D. Sebastian, MOF, personal communication.

Junction. Waters at the 'Junction' station are a mixture of Parsnip and Finlay reach outflows, and strong summer winds from either south to north or east to west out of the Peace Canyon create a well-mixed epilimnion that ranges between 20-25 m in depth. That Junction station is well situated within the 'zone of mixing' of both Finlay and Parsnip waters is apparent by comparing the average seasonal values of a conservative variable like TDS where the average value for Parsnip was 88 mg/m", and for Finlay 119 mg/m^3, with the average of the two basins = 103 mg/m^3, very similar to the measured Junction value - 100 mg/m^3. The average epilimnetic depth (22 m) at Junction is greater than Parsnip but less than Finlay, and water transparency (Secchi

depth) was the lowest average in the reservoir in 2000, and 2nd lowest in 1999. The average ranking of key variables showed Junction station as 2nd most productive in 1999 but 4th in 2000, with a moderately low phytoplankton abundance and biomass. Junction station had a higher zooplankton biomass than Parsnip but lower than Finlay Reach. Primary production at Junction station was 2nd highest in 1999 but only 4th highest in 2000. There is obviously enough mixing of nitrate-poor Finlay water with nitrate-rich Parsnip water to prevent nitrate depletion here, but nitrate values in August were next to Finlay the lowest in the reservoir. The NO_3:TDP ratio at Junction 12.9 was 2nd lowest among stations in 2000, but higher in 1999 - 17.0. At Junction station, like stations in Parsnip and Finlay reaches, higher turbidity with greater sub-surface light attenuation is likely one of the more significant factors limiting primary production.

Peace Reach - Clearwater. Williston's east basin or Peace Reach is much deeper, narrower and more wind mixed than either Parsnip or Finlay reaches. At Clearwater station, 50 km east of Junction station, the average epilimnetic depth are >30 m and maximum epilimnion temperatures range between 13-15° C. Clearwater station sampled mid-basin waters and ranked 5th or last, as one of the least productive regions in Williston Reservoir. Clearwater had the lowest average bacteria, APP, and phytoplankton densities, and the 2nd lowest zooplankton abundance and biomass. But Clearwater in 2000 had the 2nd highest average primary production and, next to Finlay, the 2nd most efficient production (P/B). There does not appear to be any nutrient limitation of phytoplankton at Clearwater with a NO_3:TDP ratio of 21 in 1999, highest among stations, and 15.8 or 3rd in 2000. Were in not for the prevalence of strong invasive winds, great depth of epilimnion and strong mixing episodes, that force phytoplankton to spend less time in optimal light conditions, primary production at Clearwater should theoretically be the highest in the system. Thus light limitation and mixing depth are considered limiting factors for production here and at Forebay station.

Peace Reach - Forebay. Forebay station sampled waters at the most eastern sector and deepest (>190 m) part of the Peace Canyon basin just adjacent to the Bennett Dam. There was a striking similarity between Forebay and Clearwater in nearly all measured variables, the only notable departures being a greater epilimnetic depth >40 m, a higher maximum temperature in 2000, a greater turbidity, and a 1 m lower average Secchi depth in 1999 and 2000. The productive potentials as assessed by key variables ranked Forebay 5th or least productive among Williston stations in 1999, but 2nd highest in 2000. In 2000 the highest APP populations were at Forebay, but the 4th highest bacterial abundance. Phytoplankton abundance and biomass were 2nd and 3rd highest in 2000, but 2nd lowest in 1999. Zooplankton was abundant at Forebay ranking either 1st or 2" both years, but primary production was lowest in the reservoir in both years. Forebay like Clearwater station, showed no potential nutrient shortages with the 2nd highest NO_3:TDP ratio in both years. Turbidity and low average Secchi depths create a shallow compensation depth here, that when coupled with strong mixing and a very deep epilimnion create sub-optimal light condition for phytoplankton that likely severely limits production here during the growing season. Advection of biogenic materials eastward by the large water discharge from the dam during the growing season, coupled with potential withdrawals from the epilimnion in autumn with

increasing discharge, may be one of the mechanisms important in maintaining phyto- and zooplankton biomass at Forebay. This factor could also be responsible for the observed high variance in key variables between years at this station.

Nutrients and trophic state.

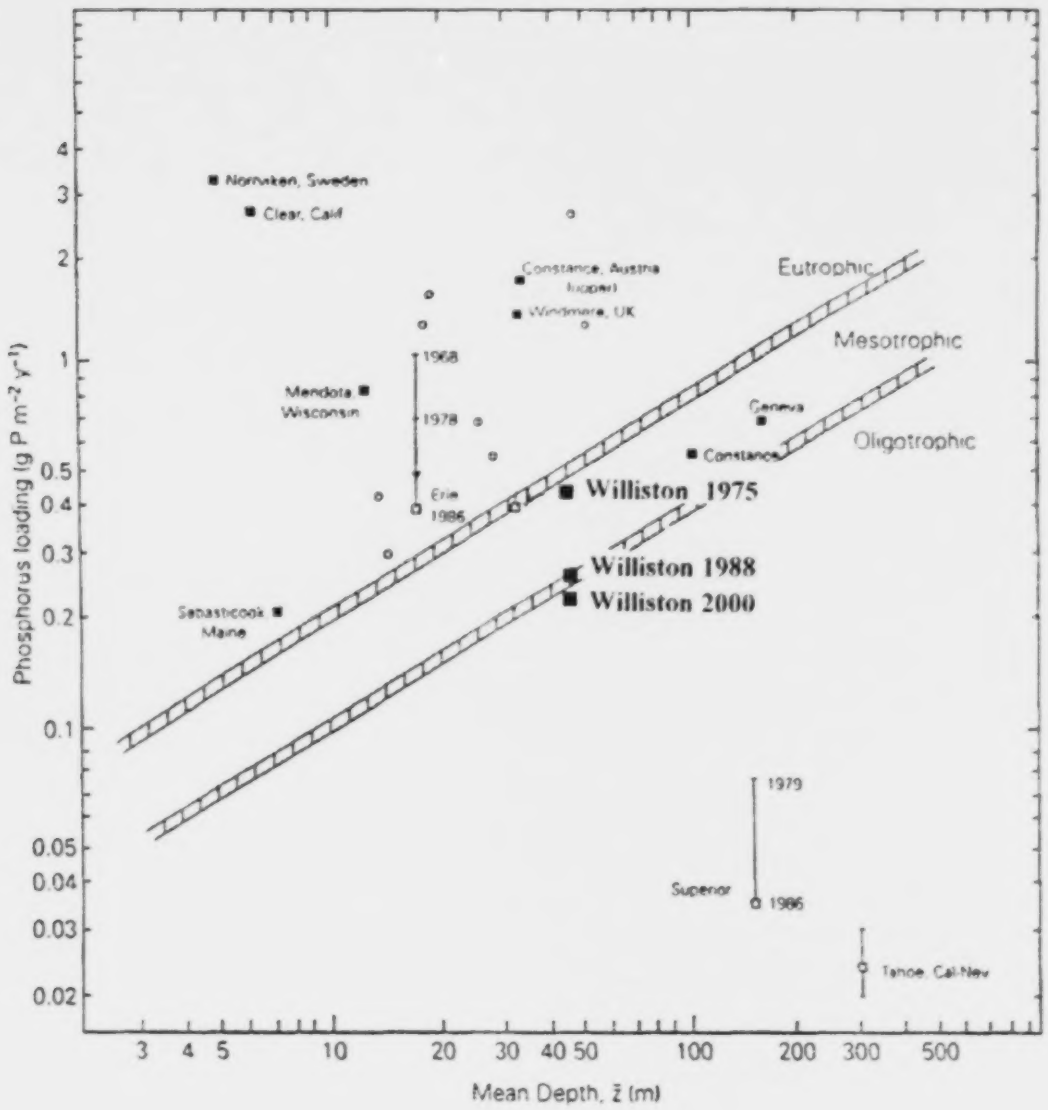
Nutrients. Several of the more obvious elements of analysis missing in past limnological assessments of Williston Reservoir were those related to nutrient loading and to seasonal primary production, i.e. photosynthetic rates (PR). Stockner (1998, BC Hydro, unpublished data) assembled autumn TP and TN data from earlier surveys (1975, 1988), and demonstrated that the reservoir over this 13 yr period showed rather striking declines in concentrations of both TN and TP (Table 6). The 1999/2000 monitoring program has provided current TP and TN values to compare with these earlier values, and these data suggest that there has been no further reductions in ambient values from the lows seen in 1988, and that current concentration appear to have slightly increased. Based on the premise that ambient TN and TP concentrations are correlated with system productivity, then it appears likely that production in Williston has now stabilised, and has probably reached a new equilibrium with the annual N and P input (supply) and with output (losses) to discharge and sedimentation.

Table 6. TN and TP from Nov. 1975, Oct. 1988 and Nov. 1999 & 2000 at selected stations (1975 and 1988 values from *G3* EEM report, 1994).

Station	Variable	1975	1988	1999	2000
Parsnip (S3)	TN	196-315	170-180	170-220	-
	TP	5.0	4.5	7.3	5.0
Finlay (N8)	TN	128-134	80-110	100-140	-
	TP	11.0	4.0	6.0	5.0
Junction (J4)	TN	155-166	110-160	120-160	-
	TP	5	3.5	6.5	6.2
Clearwater (E4)	TN	139-171	80-150	130-140	-
	TP	5	3.5	3.5	2.0
Forebay (E13)	TN	142-228	120-180	140-180	-
	TP	5	3.5	4.6	2.2

***P-Loading and Trophic State* (Fig. 20).** Using values of TDP at spring overturn to compute an annual P-load to Williston (Vollenweider 1976), and plotting these P-loads as a function of Williston's mean depth provides another measure of the current trophic state of the reservoir - oligotrophic. The current P-load to Williston probably lies between 225-275 $gP/m^2/yr$, and likely exceeded 400 -450 $gP/m^2/yr$ in the early 1970's (Stockner 1998, BC Hydro Rep., unpublished). Despite the large margin of error associated with these estimates, the graphic does show declining loads following the 1975 'boom' period.

Fig. 20.Williston Reservoir annual P load in selected years vs mean depth (after Vollenweider 1976)



Looking at the magnitude of values of some of the 'key' biological variables gathered during the 1999 and 2000 Williston Reservoir monitor, and then comparing them with values from other BC or Yukon Territory lakes and reservoirs provides one of our most reliable measures of Williston's current trophic state. Clearly, with such low chlorophyll, phytoplankton and zooplankton biomass, coupled with extremely low primary production rates and low APP densities, the Williston Reservoir now lies well within the oligotrophic condition, in some aspects (PR, Chl., APP) close to 'ultra' oligotrophic. Owing to its geographic location and climatic setting, and its extremely short water residence time with large water level fluctuations, it is probable that the reservoir will retain in perpetuity these basic oligotrophic features. But this prognosis does not take into account possible changes in productivity that could occur because of global warming, intensive resource extractions (e.g. clear-cut logging) throughout the drainage basin, or changes in operation to stabilise water levels, or from catastrophic events like forest fires, earthquakes, etc. Any of these changes could potentially increase/decrease N and P inputs and affect system productivity (Stockner et al. 2000).

System comparisons.

***Phosphorus* vs *chlorophyll* (Figs. 21 and 22)** The picture emerging is that Williston Reservoir for the first decade after impoundment was undoubtedly a much more productive ecosystem, using abundant nutrients from land inundation and the decomposition of flooded vegetation (boom cycle). It is now apparent that after 3 decades the system has become progressively less productive, losing nutrients (N & P) through outflow and sedimentation. If one compares Williston Reservoir's 1999/2000 TP and Chl. values with BC lakes and reservoirs and with the large lakes of the Yukon River drainage basin, and with Alberta prairie lakes, it is not to surprising that Williston's 1999/2000 average TP and Chl values fit near the centre of the Yukon lakes data set, since they share some similarities of geographic and biogeoclimatic settings. Most Yukon lakes support a greater abundance of large macrozooplankton than Williston, largely because they lack large populations of planktivorous fishes, e.g. juvenile kokanee, whitefish. Therefore Yukon lakes low chlorophyll values relate more to grazing or 'top-down' control than to nutrient supply or light limitation as in Williston, i.e. 'bottom-up' (Shortreed and Stockner 1986). When one looks at the position of Williston within a relationship between TP and chlorophyll using data *only* from coastal fertilised and unfertilised BC lakes (MacIsaac & Stockner 1985), it is clear that Williston's 1999/2000 average TP value (6-7 mg/m^3) and very low chlorophyll (1.4 µg/L) fall well below the line of best fit and off-scale far to the right-hand corner of this graph (Fig. 22). But because about 50% of measured TP in Williston is inorganic particulates and likely unavailable for biogenic production, for this graph we used Williston's TDP value instead of TP and the point falls within the cluster of BC coastal, fertilised oligotrophic lakes. However, the chlorophyll values for Williston, as clearly seen in this figure, are still exceptionally low for a system of this size and geographic setting (Stockner 1987).

Fig. 21. Relationship between seasonal average TP vs Chlorophyll from a variety of BC, Alberta and Yukon Territory lakes.

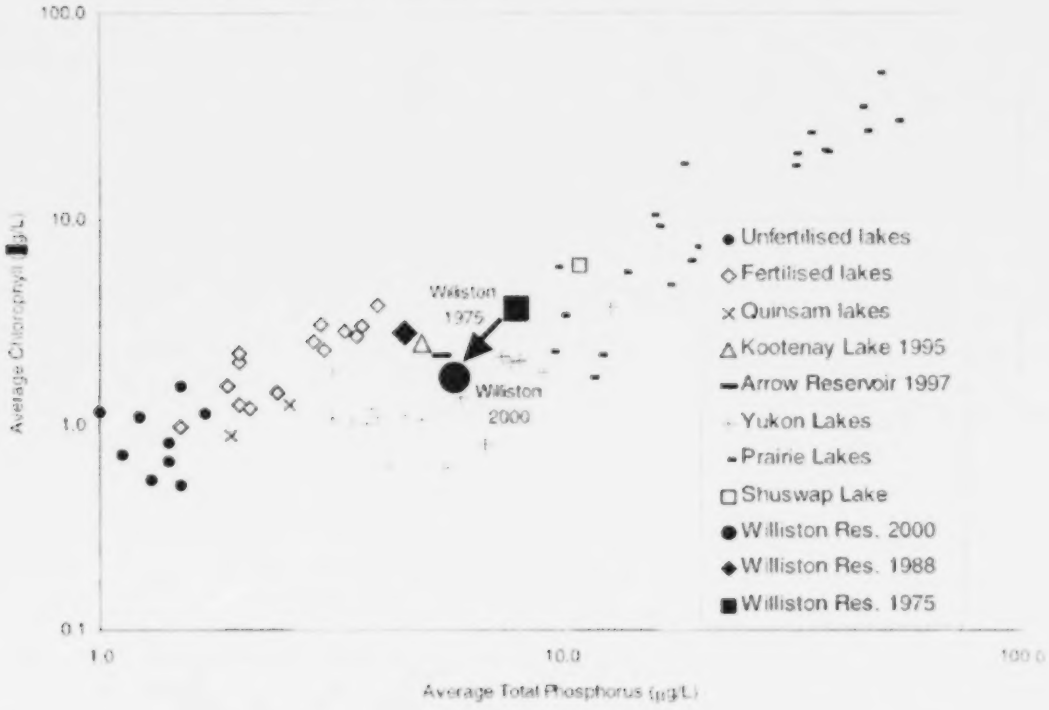
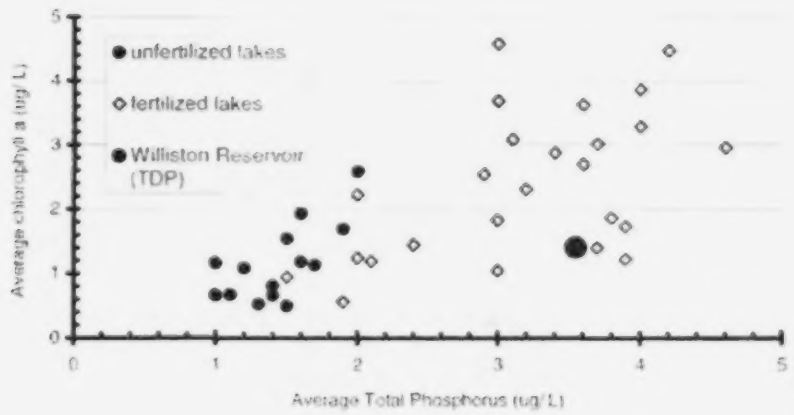


Fig. 22. Relationship between average TP and Chl for coastal fertilised and unfertilised lakes, Williston point is average TDP 2000.

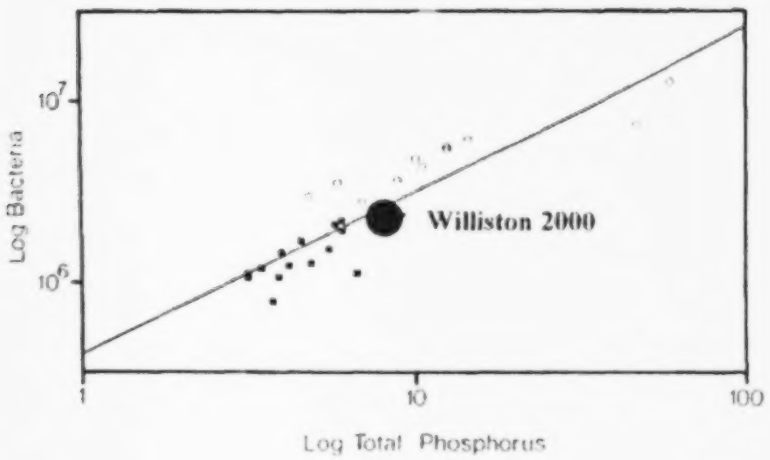


APP and Bacteria. **(Fig. 23).** The average abundance of APP in Williston was about 20 $x10^3$ cells/mL below the average of 32 $x10^3$cell/mL in BC coastal lakes (untreated) and less than half the average for Yukon basin lakes $55x10^3$ cell/mL (Stockner 1991). But the average abundance of heterotrophic free-living bacteria in Williston - 1.2 x 10^6 is higher than the coastal BC untreated lake average - 0.7 x 10^6, but lower than the average density measured in fertilized lakes 1.4 x 10^6 (Stockner and MacIsaac et al. 1996). Log plots of Williston total bacteria *vs* average 2000 TP and chlorophyll values lie on the line of best fit for Yukon basin and Quebec lakes (Shortreed and Stockner 1986) (Fig. 23). This discrepancy between APP and bacteria abundance is likely related to the poor light climate for APP in Williston and the limitation of their growth by light in such a turbid system, while heterotrophic bacteria, not being light dependent, have sufficient concentrations of organic C, N and P to sustain much larger populations.

The large bacteria populations in Parsnip Reach in May 2000 are likely the result of higher nutrient concentrations during low flow winter and early spring periods in Parsnip Reach. Nutrients from municipal and industrial (pulp and paper mill) discharges near Mackenzie help to increase help to elevate concentrations during winter, especially dissolved organic carbon (DOC), a required nutrient for sustaining bacterial growth. To attain a bacteria population in May at Parsnip station of $>3x10^6$/mL would require high concentrations of DOC, and with such cold surface temperatures growth would be very slow. Was the high population dormant or largely composed of dead cells? Is it possible that the large bacterial populations found in October and November at Forebay in are residuals of this large spring bacterial biomass from Parsnip, advected by deep currents to this sector by late fall? The answers must come from further research on bacteria, currents and hydraulic residence times in Williston.

Primary Production **(Fig. 24, Table 7).** When compared to PR estimates from other BC coastal lakes, primary production rates computed for Williston are very low, more in line with values from ultra-oligotrophic coastal lakes (Stockner 1981, 1987) (Fig. 24, Table 7). Though N limitation may reduce phytoplankton production in August in Finlay Reach, it is unlikely that Williston Reservoir is at present limited by ambient TDP concentrations. Because of the prevalence of episodic strong winds, the continual erosion of clay and silt from unstable shorelines, plus the large input of high turbidity freshets in June/July, turbid conditions persist throughout the reservoir throughout much of the growing season. Light penetration is limited to within the upper 5-10 m of the reservoir yet mixing depths in the epilimnion during protracted strong wind can extend to 15-20 m in mid-summer and even deeper ->35 m in September and October. Thus phytoplankters in a strongly mixed or isothermal lake are exposed, on average, to a much lower quantity/quality of light, and this condition is further exacerbated if the system happens to be turbid or humic-stained like Williston and Babine Lake (Stockner & Shortreed 1975). Though mixing can often replenish and/or increase available nutrient supplies, this positive aspect of mixing can quickly be negated by turbidity and poor light penetration. The very low levels of primary production measured in Williston Reservoir can largely be explained by light limitation of growth, as nutrients

Fig. 23. Average abundance of bacteria in Williston Reservoir vs average TP and chlorophyll. Line of best fit for Quebec Lakes (o) and Yukon Lakes (•) after (Shortreed and Stockner 1986).



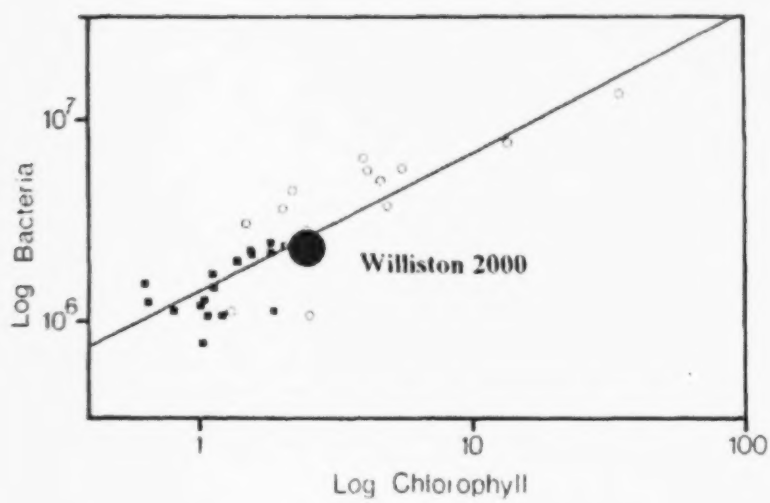
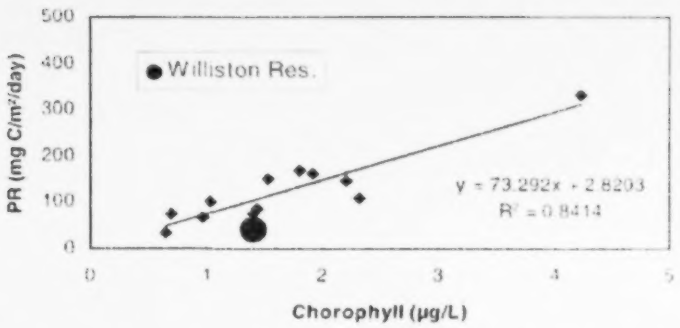


Fig. 24. Average PR vs Chl. for a variety of BC lakes (K. Shortreed, unpublished data)



are more than sufficient at most times to promote much higher primary production levels than realized. Low epilimnetic temperatures can also influence phytoplankton production rates but they are not so low during the growing season as to be a major controlling factor. It comes as no surprise that APP are the predominant phytoplankters in terms of both overall abundance and in C production (>50% of total C production) in Williston, since they are known to grow optimally under low light and nutrient conditions where they often form sub-surface plates in lakes and oceans (Stockner & Antia 1986, Stockner and Shortreed 1991). Yet APP populations are generally quite low and at densities found in ultra-oligotrophic BC lakes (Stockner and Shortreed 1991), and like other phytoplankters in Williston, they are probably also affected by turbidity and poor light conditions. Finally, the fast-flushing, short residence time of Williston must further exacerbate production potentials by export of both nutrient and biomass from the system at crucial times, e.g. fall and winter periods, reducing densities of over-wintering populations.

Table 7. Comparison of Williston size-fractionated (August) production with values from interior BC sockeye nursery lakes.

Lake/Station	Phytoplankton Carbon Production ($mgC/m^2/day$)			
	Pico-plankton	Nano-plankton	Micro-plankton	Total
	0.2-2.0 µm	2.0-20.0 µm	20.0-200 µm	
Williston Parsnip	16.3	11.3	3.9	31.5
Williston Finlay	14.9	10.3	5.6	31.0
Williston Junction	11.0	7.5	1.8	20.3
Williston Clearwater	10.8	8.5	2.0	21.3
Williston - Forebay	10.6	6.9	2.7	20.2
Williston Reservoir[1]	12.7	8.9	3.2	24.9
Okanagan Lake[2]	38	88	39	165
Babine Lake[3]	56	49	18	123
Fraser Lake[3]	53	108	175	336
Shuswap Lake[3]	41	53	47	140
Quesnel Lake[3]	41	37	24	102

1. August 2000 values; 2. Sept. 2000 values, 3.mean values (K. Shortreed, DFO, unpublished data).

It is interesting to compare Williston's August size-fractionated C production (the highest production attained in 2000!) with similar data from other BC lakes (Table 7). Once again the comparison demonstrates the extremely low C production of the Williston Reservoir that is over 10 fold lower than Fraser Lake (meso-eutrophic) and > 4 fold lower than average Babine, Shuswap and Quesnel values. Arrow Reservoir (values not shown) is the only system with comparable average total C production values and its trophic state is considered ultra-oligotrophic (Pieters et al. 2000).

Zooplankton.

In comparison to other large interior BC lakes and reservoirs, Williston Reservoir has a low total zooplankton density, but has an average proportion of cladocerans (Table 8). The seasonal zooplankton density in Williston was 6.1 mdividuals/L, very similar to the Arrow Reservoir density of 7/L (Pieters et al. 2000). Williston zooplankton densities were considerably less than the 14/L Kootenay pre-fertilisation whole lake average (Ashley et al. 1999), and the Okanagan Lake average of 18/L in 1997-00 (G. Wilson in Andrusak *et al.* 2000). Okanagan and Kootenay lakes are much more productive oligotrophic lakes than Williston. In contrast, total zooplankton density in Alouette Reservoir, a coastal reservoir bordering on 'ultra'-oligotrophic productive conditions, is <2/L (Wilson *et al.* 1999). Cladocerans accounted for approximately 10% of the total zooplankton density in Williston Reservoir, which is above their percentages in Kootenay and Okanagan Lakes (Table 8). The latter two have established *Mysid* populations that prey heavily on zooplankton, specifically on cladocerans (Grossnickle 1979, Bowers 1988).

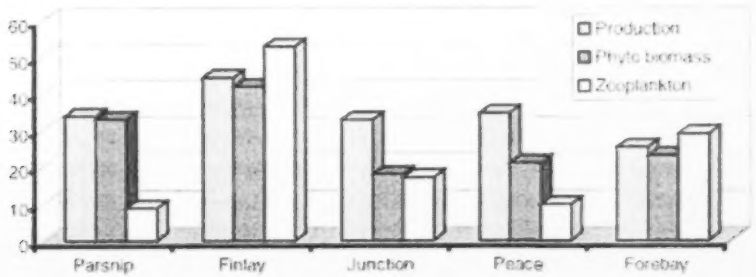
Table 8. Comparison of seasonal density of pelagic zooplankton as % of total zooplankton in Williston Reservoir and other BC lakes/reservoirs[1]

Lake/reservoir (year)	Seasonal total density (No. •/L)	No. of species	% cladocerans	% *Daphnia*	*Mysis* density (No.•/m^2)[a]
Kootenay (pre-fert, <1992)	14	11	3%[d]	<1%[d]	200-500
Kootenay (fert, 1997-99)	19	11	8%	3%	139-400
Okanagan Lake (1997-00)	18	8	5%	1.5%	333
Kalamalka Lake(1997-98)[b]	10	6	4%	1.3 %	519
Arrow Res. (prefert, 1997-98)	7	16	23%	13 %	66
Arrow Res. (fert, 1999)	12	16	26%	20%	125
Williston Res. (1999-00)	6	15	10%	9%	0
Alouette Res. (prefert, 1998)	1.3	9	20%	<< 1 %	0
Alouette Res. (fert, 1999)[c]	2.1	9	51 %	20%	0

[1]**(from - Ashley et al. 1999; Thompson and Vidmanic 1999, 2000; Wilson et al. 2000; Wilson *in:* Andrusak et al. 2000; Pieters et al. 2000).** [a] Kootenay prefert is 1980-90 running ave. and fert is 1992-96; ave. of upper and lower Arrow; Kalamalka KA1 and KA2 stations in 1998; [b]KA1 station only; [c]fertilised north basin only; [d] N mid-lake station.

If zooplankton population abundance is tightly coupled to their forage base (bottom-up control), then there should be good correspondence between phytoplankton biomass, primary production and zooplankton biomass. Both Finlay Reach and Forebay station ranked high as being the most productive stations in Williston Reservoir in 2000, and there was a good average seasonal relationship between production and plankton biomass (Fig. 25). But at Parsnip Reach station and Peace-Clearwater zooplankton biomass was considerably lower than forage potentials, while at Junction station zooplankton biomass was well matched with phytoplankton, but not with production, suggesting more influence of top-down control.

Fig. 25. Average primary production, phytoplankton and zooplankton biomass in Williston Reservoir, 2000.



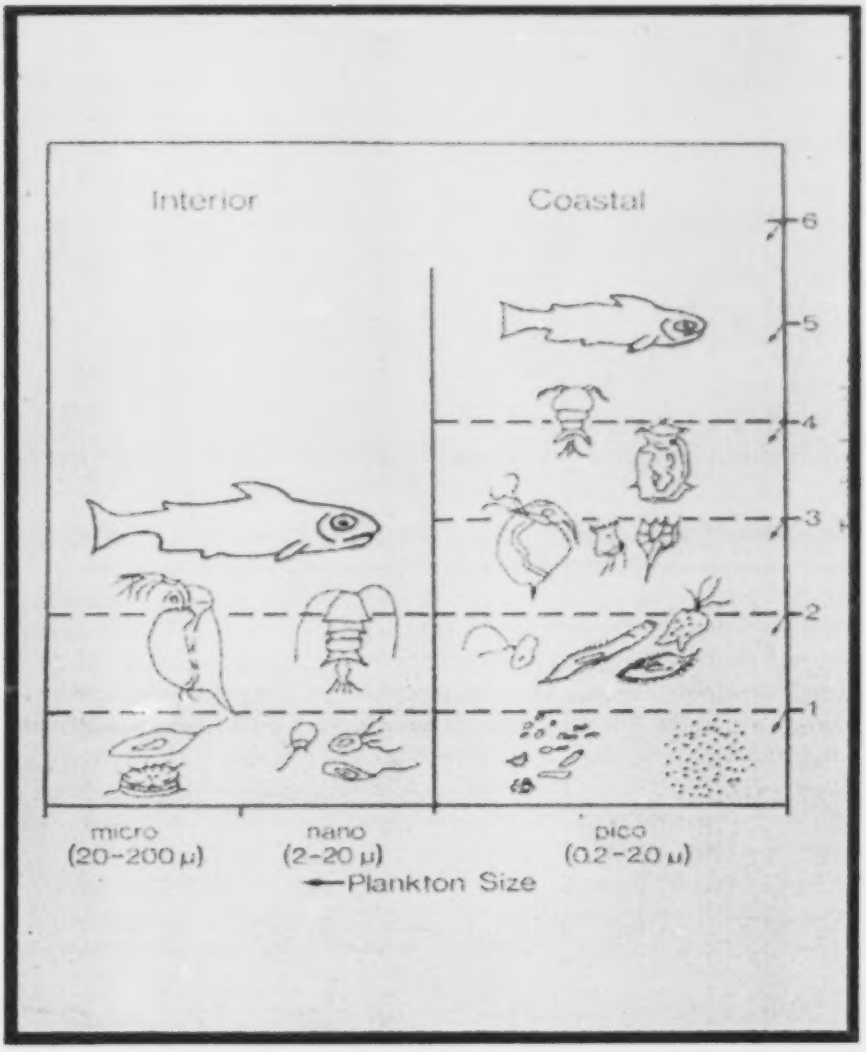
Whether these differences among stations relate biology - fish densities and grazing impacts, edibility of phytoplankton species, or to reservoir physics -mixing depths, short residence times, or advection and currents, remains speculative without further research on fish, forage and physics. Unfortunately we have little data on planktivorous fish abundance and distribution in 1999, and only unanalyzed data and a few preliminary comments from hydroacoustic transect work done in September 2000. Nonetheless this anecdotal information does support our conclusions on Williston's productive capacity (ranking) by station, with highest pelagic fish densities in the reservoir in 2000 occurring in Finlay Reach, the most productive basin and next highest in the Peace Reach (D. Sebastian, MOF, personal communication). As well analysis of past gill netting data suggests a shift in distribution from Parsnip to Finlay Reach by lake whitefish (the dominant pelagic fish). The whitefish condition factor appears to have declined, and size at age is currently is very low, again supporting the premise of a very low productive capacity for pelagic fishes in Williston (Blackman 1992).

Food webs (Fig. 26) The phytoplankton communities are the photosynthetic carbon producers that anchor the food webs of aquatic ecosystems, and that ultimately determine the trophic structure and productive potentials for fish populations. Williston is currently dominated by microbial communities, and their presence through-out much of the open water period and because of their ubiquity in oligotrophic ecosystem are one of the best indicators of the true trophic position of the Williston Reservoir - oligotrophic. The predominance of the picoplankter *Synechococcus* sp. and a diverse group of nano-flagellates and other small nano-plankters and small ciliates, confirms

the predominant role of 'microbial food webs' in mediating carbon metabolism, nutrient fluxes and carbon flows in all Williston reaches (Stockner and Porter 1988; Stockner and Maclsaac 1996). Results of 2 size-fractionated primary production experiments in August and September 2000 confirm the overwhelming metabolic contribution (>85% of total daily C production) that pico and nano-phytoplankton make to total C production in the system, and in sustaining the carbon base of food webs. The importance of picoplankton cannot be overstated, contributing 45-50 % of the total C production at all stations. Unfortunately, the predominance of microbial food webs in low production reservoirs like Arrow and Williston also portend a low benthic/pelagic coupling (low benthos production), low forage production (macro-zooplankton) and sub-optimal rearing conditions for kokanee, whitefish and other salmonid piscivores, e.g. rainbow, bull trout. This is because microbial food webs are made up of multiple pathways of trophic exchange, and at each carbon transfer (prey-predator) energy is dissipated and metabolic costs (CO_2) are high. Therefore, these food webs are generally viewed as inefficient, especially so when compared to 'classic,' short pathway food chains, e.g. micro-phytoplankton—macro-zooplankton—fish. A schematic illustration of how food chain complexities can impact pelagic fish production and account for differences in carbon flows between ultra-oligotrophic BC coastal, e.g. Great Central Lake, and more productive meso-oligotrophic interior BC lakes, e.g. Shuswap Lake, is shown in Fig. 26.

Though Williston Reservoir is by geography an 'interior' ecosystem, and should show production values similar to the Yukon lakes, the fact that it is a fast-flushing, turbid reservoir with a non-functional littoral zone has greatly reduced C production and created an ecosystem best mimicked by fast-flushing 'coastal,' oligotrophic lakes!

Fig. 26. Schematic diagram of food-web processes in ultra-oligotrophic 'coastal' and meso-oligotrophic 'interior' BC lakes, plotted by size of predominant phytoplankters vs number of trophic levels (transfers) (after Stockner 1987).



SUMMARY

Williston Reservoir, BC's largest reservoir is a physically complex and highly dynamic, wind driven ecosystem, strongly influenced by the amalgamation of 3 large and diverse drainage basins - Peace, Finlay, and Parsnip, each differing in biogeoclimatic setting. Despite such potential for inherent complexity there was a remarkable similarity among physico-chemical and biological variables assessed during the 2 yr monitoring program. By comparing information on current conditions with early limnological data we can now confirm that the reservoir's productive capacity has declined from its early more productive 'boom' phase (1968-80), and has entered its present low production phase, and is now likely in equilibrium with annual nutrient inputs and losses. Standing stock of biomass at all trophic levels is *very* low, and rates of primary production are much lower than measured in other, similar large interior BC lakes, and well within the range found in ultra-oligotrophic fast-flushing BC coastal lakes. There are a number of factors to account for such low production, among the more significant are: short water residence times (large discharge), and abnormally large drawdown (11m) with associated shoreline instabilities and erosion, high turbidity (high light attenuation), deep and variable mixed layer depth, and a shallow euphotic zone. These factors in concert with strong, invasive winds and turbid inflows severely limit light quality and quantity in surface layers and lowers total system biogenic production within both the pelagic and littoral zones. Most all of the major chemical and biological variables monitored in 1999-2000 all point to Williston's current productive capacity as being well within the low sector (ultra) of the **oligotrophic** condition.

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REFERENCES

Andrusak, H., Sebastian, D., McGregor, I., Matthews, S., Smith, D., Ashley, K., Pollard, S., Scholten, G., Stockner, J., Ward, P., Kirk, R., Lasenby, D., Webster, J., Whall, J., Wilson, G., Yassien, H. 2000. Okanagan Lake Action Plan Year 4 (2000) Report. Fisheries Project Report No. RD 83. BC Ministry of Fisheries, Fisheries Management Branch.

Ashley, K.I., Thompson, L.C., Lombard, D., Yang, Jing-Rong, Pick, F.R., Hamilton, P.B., Lasenby, D.C., Smokorowski, K.E., Sebastian, D., and G. Scholten. 1999. Kootenay Lake Fertilization Experiment - Year 5 (1996/97) Report. BC Ministry of Environment, Lands and Parks, Fisheries Project Rep. No. RD65.

Barrett, D.T., and T.G. Halsey. 1985. Fisheries resources and fisheries potential of Williston Reservoir and its tributary streams. Vol. I. Fisheries resources and fisheries potential of Williston Reservoir. Prov. B.C. Fish. Br. Tech. Circ. No. 68:40p.

BC Hydro. 1996. W.A.C. Bennett Dam and G.M. Shrum generating station (Peace River power). Informational pamphlet. BC Hydro, Burnaby, BC.

BC Hydro. 1988. Williston Reservoir raising: Environmental overview. Environmental Services, Systems Operations and Maintenance Division, Rep. No. ES-118. BC Hydro, Burnaby, BC.

BC Research. 1976. Limnological studies of Williston Lake during summer and fall, 1975. Project No. 1711. Prepared for Department of Environment, Victoria, BC.

BC Research. 1977. Limnology of Arrow, McNaughton, Upper Campbell, and Williston Lakes. Project No. 1-05-807. Prepared for BC Hydro Power and Authority, Vancouver, BC.

Blackman, B.G. 1992. Fisheries resources of Williston Reservoir twenty years after impoundment. Peace/Williston Fish and Wildlife Compensation Program report No. 239. 35pp plus appendices.

Bowers, J.A. 1988. Diel vertical migration of the opossum shrimp *Mysis relicta* in Lake Superior: Observations and sampling from the Johnson-Sea-Link II submersible. Bull. Mar. Sci. 43:730-738.

Brooks, J.L. 1959. Cladocera, pp. 587-656, In W.T. Edmondson [Ed.], Fresh-water Biology, John Wiley and Sons, New York.

Canter-Lund, H., and J.W.G. Lund. 1995. Freshwater Algae - their microscopic world explored. BioPress Ltd., Bristol, UK, 360p.

Deevey, Jr. E.S., and G.B. Deevey. 1971. The American species of *Eubosmina* Seligo (Crustacea, Cladocera). Limnol. Oceanogr. 16: 201-218.

Fleming, J.O., McAdam, S. and R. Pulfer. 1991 (MS). Williston fisheries compensation study: Limnology and water quality program 1988 Environmental Resources Division. Unpublished data. BC Hydro, Burnaby, BC.

G3 Consulting Ltd. 1994. Environmental effects monitoring program. Williston Reservoir, Pre-design report. Volume 1, Prepared for Finlay Forest Industries and Fletcher Challenge Canada Ltd., Mackenzie Pulp, Richmond, BC.

Grossnickle, N.E. 1979. Nocturnal feeding patterns of *Mysis relicta* in Lake Michigan, based on gut content fluorescence. Limnol. Oceanogr. 24: 777-780.

Hanson, J.M. and R.H. Peters. 1984. Empirical prediction of crustacean zooplankton biomass and profundal macro-benthos biomass in lakes. Can. J. Fish. Aquat. Sci. 41:439-445.

Hirst, S.M. 1991. Impacts of the operation of existing hydroelectric developments on fishery resources in British Columbia. Volume 2. Inland fisheries. Can. MS Rep. Fish. Aquat. Sci. 2093: 200p.

Lund J.G., Kipling C. and E.D. LeCren. 1958. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. *Hydrobiologia* 11: 143-170.

Maclean, L. 1998. G.M. Shrum and Peace Canyon projects. Facility field guide. Power Supplies and Environmental Services. BC Hydro, Burnaby, BC.

McCauley, E. 1984. The estimation of the abundance and biomass of zooplankton in samples. In: Downing, J.D. and F. H. Rigler (Eds) A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters - 2nd Ed., Blackwell Scientific Publications, London.

Maclsaac, E.A., K.S. Shortreed, and J.G. Stockner. 1981. Seasonal distribution of bacterioplankton numbers and activities in eight fertilized or untreated oligotrophic British Columbia lakes. Can. Tech. Rep. Fish. Aquat. Sci. No. 994: 43p.

Maclsaac, E.A. and J.G. Stockner. 1985. Current trophic state and potential impacts of coal mine development on productivity of Middle Quinsam and Long lakes. Can. Tec. Rep. Fish Aquat. Sci. No. 1381: 63p.

McQuaker, N.R. 1994. British Columbia environmental laboratory manual for the analysis of water, wastewater, sediment and biological materials 1994 edition. Ministry of Environment, Lands and Parks. Victoria, BC.

Ministry of Environment. 1983. Finlay-Omineca strategic environmental plan. Technical Rep. Panning and Assessment Branch. 435p. Ministry of Environment, Victoria, BC.

Pieters, R., L. Thompson, L. Vidmanic, M. Roushorne, J. Stockner, K. Hall, M. Young, S. Pond, M. Derham, S. Pond, K. Ashley, B. Lindsay, G. Lawrence, H. Andrusak, D. Sebastian and G. Scholten. 2000. Arrow Reservoir Fertilization Experiment Year 1 (1999/2000) Report. Report RD 82. Fisheries Branch. Ministry of Environment Lands and Parks. Victoria, B.C.

Shortreed, K.S and J.G. Stockner. 1986. Trophic status of 19 sub-arctic lakes in the Yukon territories. Can. J. Fish. Aquat. Sci. 43: 797-805.

Shortreed, K.S. and J.G. Stockner. 1990. Effect of nutrient additions on lower trophic levels of an oligotrophic lake with a seasonal hypolimnetic chlorophyll maximum. Can. J. Fish. Aquat. Sci. 47: 262-273.

Shortreed, K.S., J.M.B. Hume, and J.G. Stockner. 2000. Using photosynthetic rates to estimate the juvenile sockeye rearing capacity of British Columbia lakes, pp. 505-521. In: E. Knudsen + 4 others, (Eds). Sustainable Fisheries Management, Pacific Salmon. CRC, Lewis Pub. 724p.

Stockner, J.G. 1987. Lake fertilization: The enrichment cycle and lake sockeye salmon (Oncorhynchus nerka) production, p. 198-215. In: H.D. Smith, L. Margolis and C.C. Wood (eds.). Sockeye salmon (Oncorhynchus nerka) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96, 486 p.

Stockner, J.G. 1998. Williston Reservoir. Technical comment on current state of aquatic habitat (nutrients, biological production), factors limiting biological production, and recommendations for monitoring. Prepared for Peace/Williston Fish and Wildlife Compensation Program. Prince George, BC.

Stockner, J.G. 1991. Autotrophic picoplankton in freshwater ecosystems: The view from the summit. Int. Rev. gesamten Hydrobiol. 76: 483-492.

Stockner, J.G. and N.J. Antia. 1986. Algal picoplankton from marine and freshwater ecosystems: a multidisciplinary perspective. Can. J. Fish. Aquat. Sci. 43: 2472-2503.

Stockner J.G. and A.R. Langston. 2000. The Limnology of Williston Reservoir: 1999 monitoring program. Peace/Williston Fish and Wildlife Compensation Program Report No. 214. 19p (+appendices.

Stockner J.G. and K.G. Porter. 1988. Microbial food webs in freshwater planktonic ecosystems, pp 71-84, In: Carpenter S.R. (Ed), Complex interactions in lake communities, Springer Verlag, New York, NY

Stockner, J.G., and K.S. Shortreed. 1975. Phytoplankton succession and primary production in Babine Lake, British Columbia. J. Fish. Res. Board Can. 32: 2413-2427.

Stockner, J.G. and K.S. Shortreed. 1991. Phototrophic picoplankton: community composition, abundance and distribution across a gradient of oligotrophic British Columbia and Yukon Territory lakes Int. Rev. gesamten Hydrobiol. 76: 581-601.

Stockner, J.G., and K.S. Shortreed 1994. Autotrophic picoplankton community dynamics in a pre-alpine lake in British Columbia, Canada. Hydrobiologia 274: 133-142.

Stockner, J.G., and E.A. Maclsaac. 1996. The British Columbia Lake fertilization program: overview after two decades of salmon enhancement. Reg. Rivers. 12: 344-356.

Stockner, J.G., E. Rydin, and P. Hyenstrand. 2000. Cultural oligotrophication: causes and consequences for fisheries resources. Fisheries 25: 7-14.

Strickland, J.D.H. 1960. Measuring the production of marine phytoplankton. Bull. Fish. Res. Bd. Can. 122, 173p.

Thompson, L.C. and L. Vidmanic. 1999. Kootenay Lake fertilization experiment - Year 7 (1998/1990) report: Responses of zooplankton, kokanee salmon and rainbow trout. Prepared for the Fisheries Branch, Ministry of Environment, Lands and Parks, Vancouver, BC. 68p.

Thompson, L.C. and L. Vidmanic. 2000. Kootenay Lake fertilization experiment - Year 8 (1999) report: Responses of zooplankton and *Mysis relicta*. Prepared for the Fisheries Branch, Ministry of Environment, Lands and Parks, Vancouver, BC. 45p.

Utermohl, H. 1958. Zur Vervollkommnung der quantitativen Phytoplankton methodik. Int. Verein. theor. angew. Limnologie, Mitteilungen No. 9.

Vollenweider, R.A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication studies. Mem. Ist. Ital. Idrobiol.33: 53-83.

Wilson, G.A., Land, R.W., Ashley, A., Berkhout, T., Pick, F., McCusker, M., Scholten, G., and D. Sebastian. 2000. The Alouette Reservoir Fertilization Experiment: Year Two (1999) Report: The first summer of fertilization. BC Ministry of Fisheries, Project Rep. No. RD85.

Wilson, M.S. 1959. Calanoida. pp. 738-794, In: W.T. Edmondson [Ed.], Fresh-water Biology, Johns Wiley and Sons, New York.

Wilson, M.S. and H.C. Yeatman. 1956. Free-Living Copepoda. In: W.T. Edmondson [Ed.], Fresh-Water Biology, Johns Wiley and Sons, New York.

Yeatman, H.C. 1959. Cyclopoida, pp. 795-861, In: W.T. Edmondson [Ed.], Fresh-Water Biology, Johns Wiley and Sons, New York.

Appendix A

(Zooplankton and Phytoplankton Species List)

Williston Reservoir Zooplankton species.

Cladocerans
EUBOSMINA longispina
DIAPHANOSOMA leuchtenbergianum
LEPTODORA kindtii
DAPHNIA galeata mendotae
DAPHNIA pulex
DAPHNIA longiremis
HOLOPEDIUM gibberum

Copepods
CYCLOPS bicuspidatus thomasi
CYCLOPS scutifer
HETEROCOPE septentrionalis
EPISCHURA nevadensis
DIAPTOMUS ashlandi
DIAPTOMUS pribilofensis
DIAPTOMUS sicilis
DIAPTOMUS denticornis

Williston Reservoir Phytoplankton species, codes and biovolumes.

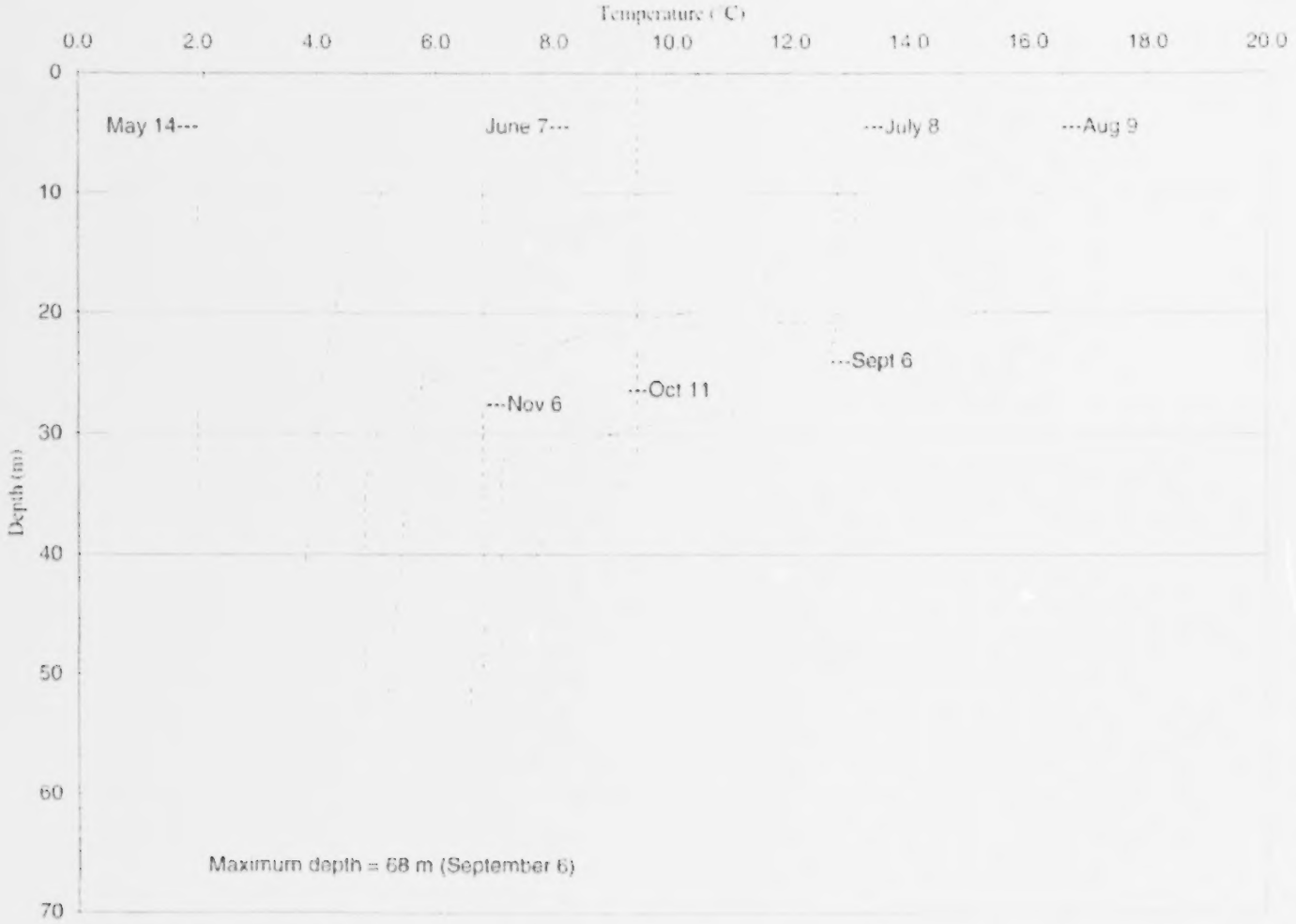
Code	Class	Bvol.	Genus & Species
Bacillariophytes - diatoms			
AM	Bacillariophyte	80	Achnanthes sp
AY	Bacillariophyte	100	Asterionella formosa varl
AZ	Bacillariophyte	120	Asterionella formosa var2
CP	Bacillariophyte	200	Cocconeis sp.
CU	Bacillariophyte	500	Cyclotella bodanica
CZ	Bacillariophyte	350	Cyclotella comta
CJ	Bacillariophyte	350	Ceratoneis sp.
CS	Bacillariophyte	150	Cyclotella stelligera
CW	Bacillariophyte	50	Cyclotella glomerata
CT	Bacillariophyte	150	Cyclotella sp
CM	Bacillariophyte	500	Cymbella sp. (large)
CO	Bacillariophyte	250	Cymbella sp.
DF	Bacillariophyte	150	Diatoma sp.
EV	Bacillariophyte	250	Eunotia sp.
FF	Bacillariophyte	80	Fragilaria construens
FC	Bacillariophyte	120	Fragilaria crotonensis
FG	Bacillariophyte	100	Fragilaria capucina
GG	Bacillariophyte	750	Gomphonema sp.
MD	Bacillariophyte	350	Aulicoseira distans
MI	Bacillariophyte	200	Aulicoseira italica
MJ	Bacillariophyte	250	Aulicoseira granulata

Code	Class	Bvol.	Genus & Species
MZ	Bacillariophyte	350	Aulicoseira sp.
NV	Bacillariophyte	500	Navicula sp.
NZ	Bacillariophyte	200	Nitzschia sp.
RC	Bacillariophyte	50	Rhizosolenia sp.
SH	Bacillariophyte	500	Stephanodiscus hantschii.
SE	Bacillariophyte	1500	Stephanodiscus sp.
SN	Bacillariophyte	100	Fragilaria acus
SO	Bacillariophyte	150	Fragilaria angustissima
SU	Bacillariophyte	1000	Fragilaria ulna
SS	Bacillariophyte	500	Suriella
SR	Bacillariophyte	250	Fragilaria sp.
PI	Bacillariophyte	2000	Pinnularia sp.
TF	Bacillariophyte	500	Tabellaria fenestrata
TB	Bacillariophyte	500	Tabellaria flocculosa
DL	Bacillariophyte	250	Diploneis sp.
Chryso- Cryptophyte flagellates			
BS	Chryso-cryptophyte	200	Bitrichia sp.
CH	Chryso-cryptophyte	250	Chilomonas sp.
XX	Chryso-cryptophyte	20	Chromulina spl
CA	Chryso-cryptophyte	150	Chroomonas acuta
YO	Chryso-cryptophyte	500	Chryptomonas sp.
CC	Chryso-cryptophyte	75	Chrysochromulina sp.
DN	Chryso-cryptophyte	150	Dinobryon spl
DO	Chryso-cryptophyte	200	Dinobryon sp2
KA	Chryso-cryptophyte	50	Kephyrion sp.
IS	Chryso-cryptophyte	200	Isthmochloron
MH	Chryso-cryptophyte	500	Mallomonas spl
MG	Chryso-cryptophyte	700	Mallomonas sp2
SX	Chryso-cryptophyte	75	Stenokalyx
YZ	Chryso-cryptophyte	15	Small microflagellates
OC	Chryso-cryptophyte	250	Ochromonas sp.
PT	Chryso-cryptophyte	100	Pseudokephrion sp.
PP	Chryso-cryptophyte	150	Pseudopedinella sp.
CI	Chryso-cryptophyte	75	Chrysoikos sp.
SY	Chryso-cryptophyte	700	Synura
RO	Chryso-cryptophyte	100	Rhodomonas sp.
CF	Chryso-cryptophyte	250	Chrysidiastrum
Dinophytes			
GY	Dinophyte	500	Gymnodinium spl
GZ	Dinophyte	1500	Gymnodinium sp2
CE	Dinophyte	5000	Ceratium
PJ	Dinophyte	350	Peridinium spl
PK	Dinophyte	700	Peridinium sp2

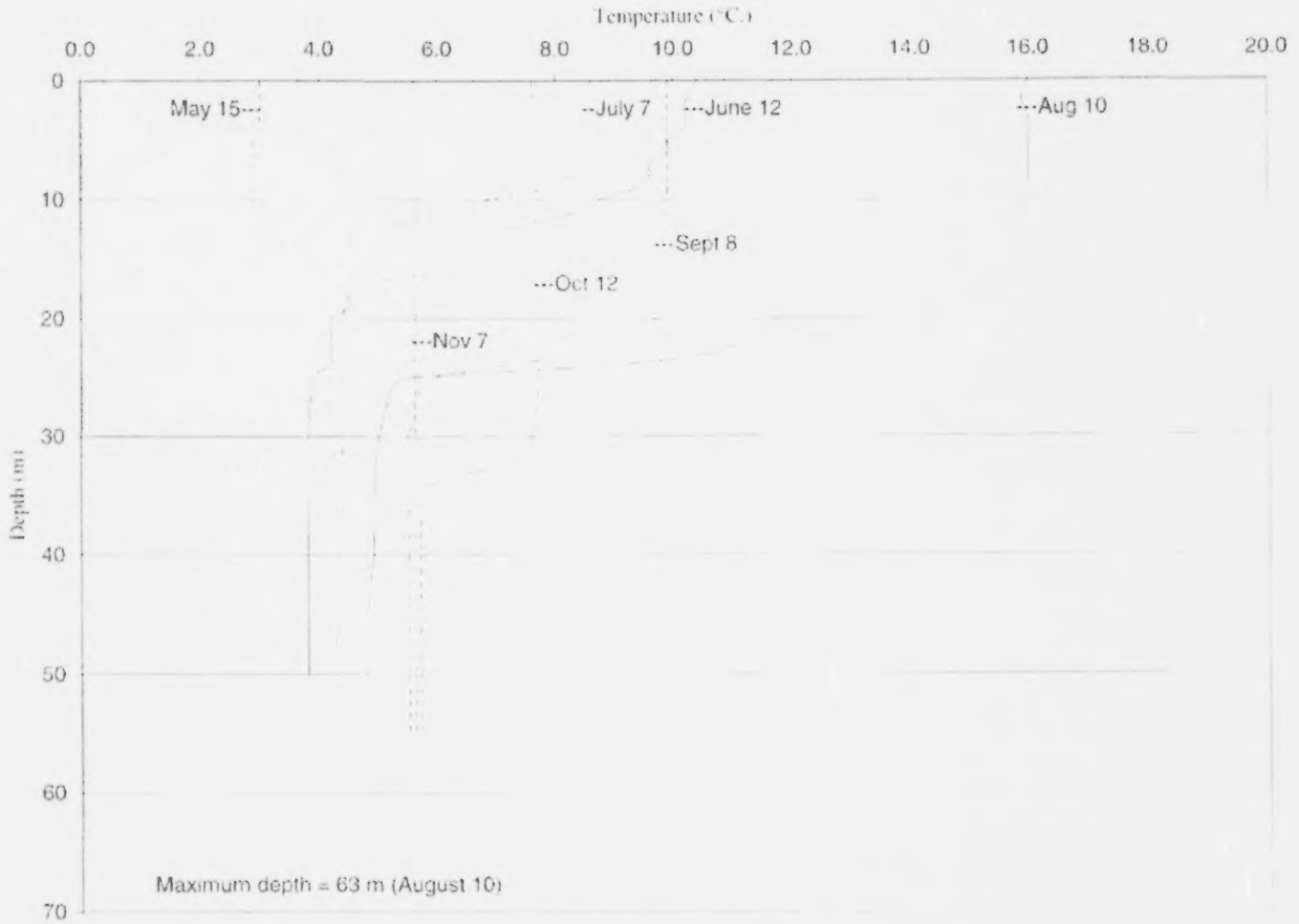
Code	Class	Bvol.	Genus & Species
Chlorophytes			
XC	Chlorophyte	80	Ankistrodesmus sp.
CX	Chlorophyte	150	Coccomyxa sp.
CL	Chlorophyte	500	Coelastrum sp.
CN	Chlorophyte	500	Cosmarium sp.
CK	Chlorophyte	200	Crucigenia sp.
XU	Chlorophyte	700	Crucigeniella apiculata
DI	Chlorophyte	900	Dichtyosphaerium
LA	Chlorophyte	30	Langerheimia
EL	Chlorophyte	250	Elakatothrix sp3
EU	Chlorophyte	2500	Euglena
GO	Chlorophyte	500	Gonium
OO	Chlorophyte	500	Oocystis sp.
SI	Chlorophyte	60	Scenedesmus sp.
SD	Chlorophyte	1500	Staurodesmus sp.
QD	Chlorophyte	250	Quadrigula
UL	Chlorophyte	700	Ulothrix
CD	Chlorophyte	150	Closteriopsis
MO	Chlorophyte	200	Monoraphidium
NE	Chlorophyte	350	Nephrocytium
ST	Chlorophyte	1000	Staurastrum sp.
PL	Chlorophyte	350	Planctonema sp.
PA	Chlorophyte	1000	Planctosphaeria
PS	Chlorophyte	100	Paulschultzia sp.
CB	Chlorophyte	20	Chlorella
KI	Chlorophyte	50	Kirchneriella sp.
PE	Chlorophyte	1000	Pediastrum sp.
PA	Chlorophyte	1500	Pandorina sp.
TE	Chlorophyte	50	Tetraedron
VO	Chlorophyte	4000	Volvox
XI	Chlorophyte	700	Xanthidium
Cyanophytes			
AB	Cyanophyte	300	Anabaena sp
AC	Cyanophyte	900	Anabaena circinalis
AH	Cyanophyte	100	Aphanothecae sp.
AP	Cyanophyte	1500	Aphanizomenon sp.
MS	Cyanophyte	20	Merismopedia sp.
ZN	Cyanophyte	20	Oscillatoria sp2
ZO	Cyanophyte	350	Oscillatoria limnetica
SC	Cyanophyte	5	Synechococcus sp. (<2 um)
CY	Cyanophyte	10	Synechocystis

Appendix B

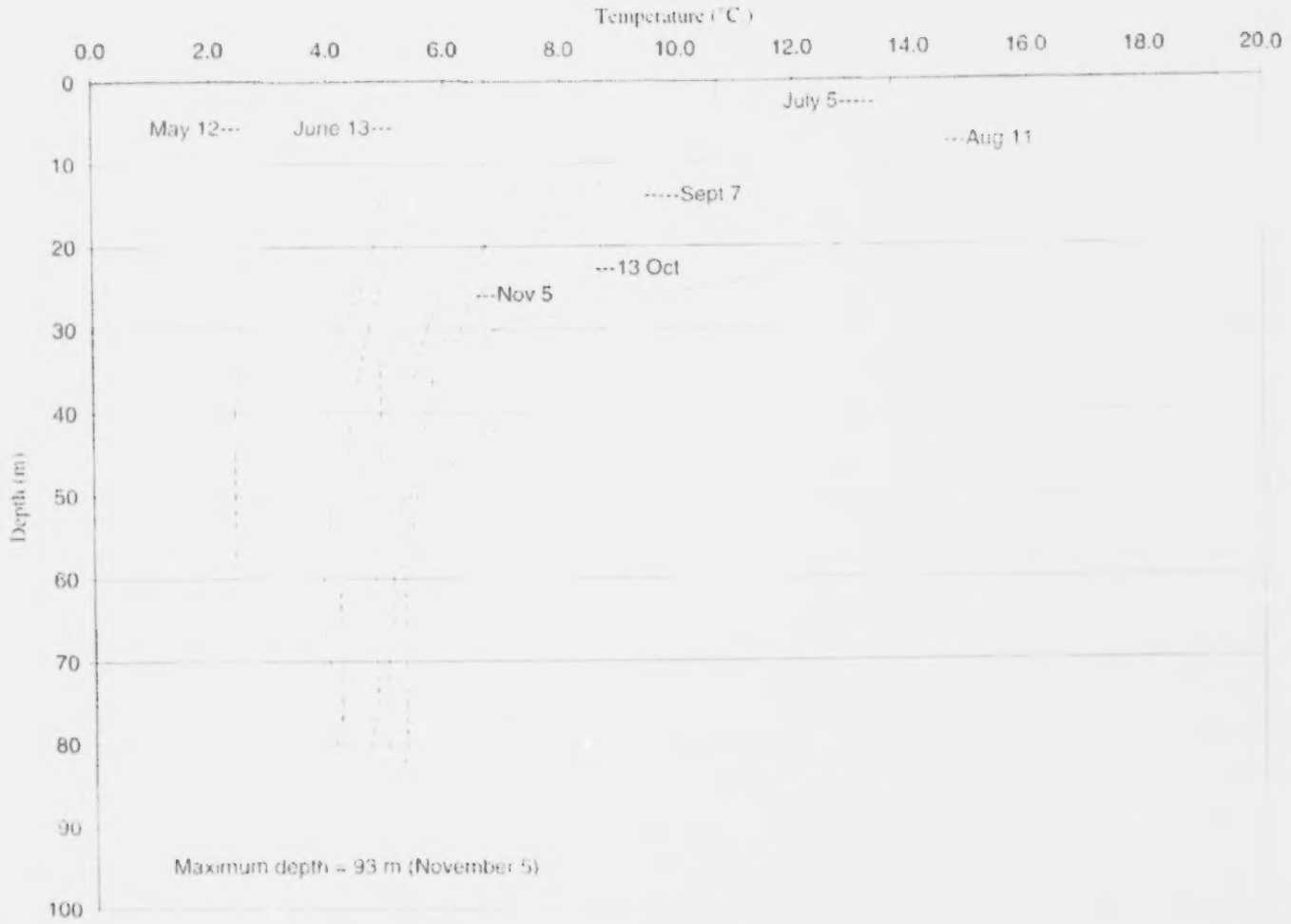
(Seasonal temperature and oxygen versus depth profiles)



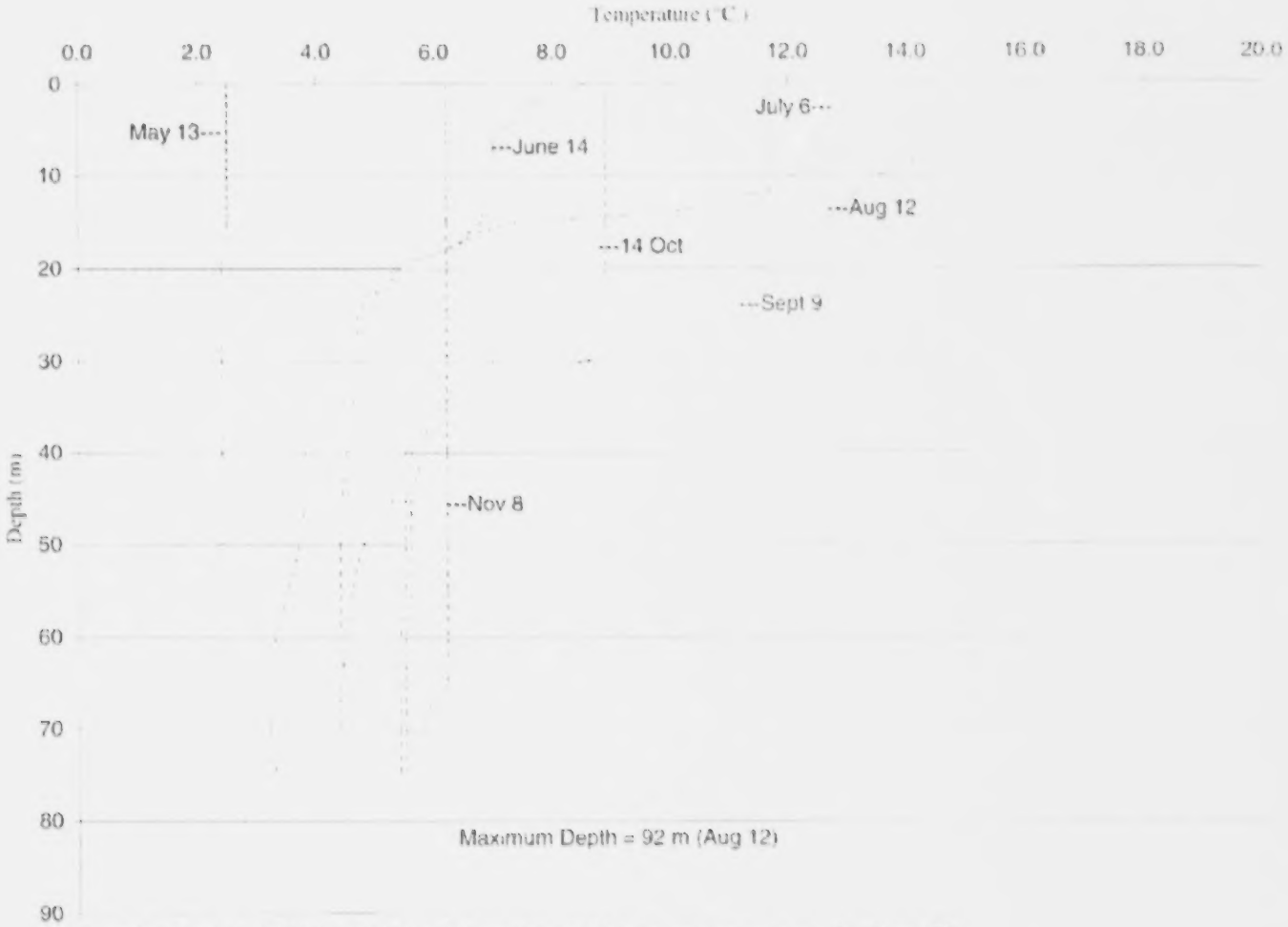
Finlay Reach station (E234184) May to November 2000 temperature versus depth profile.



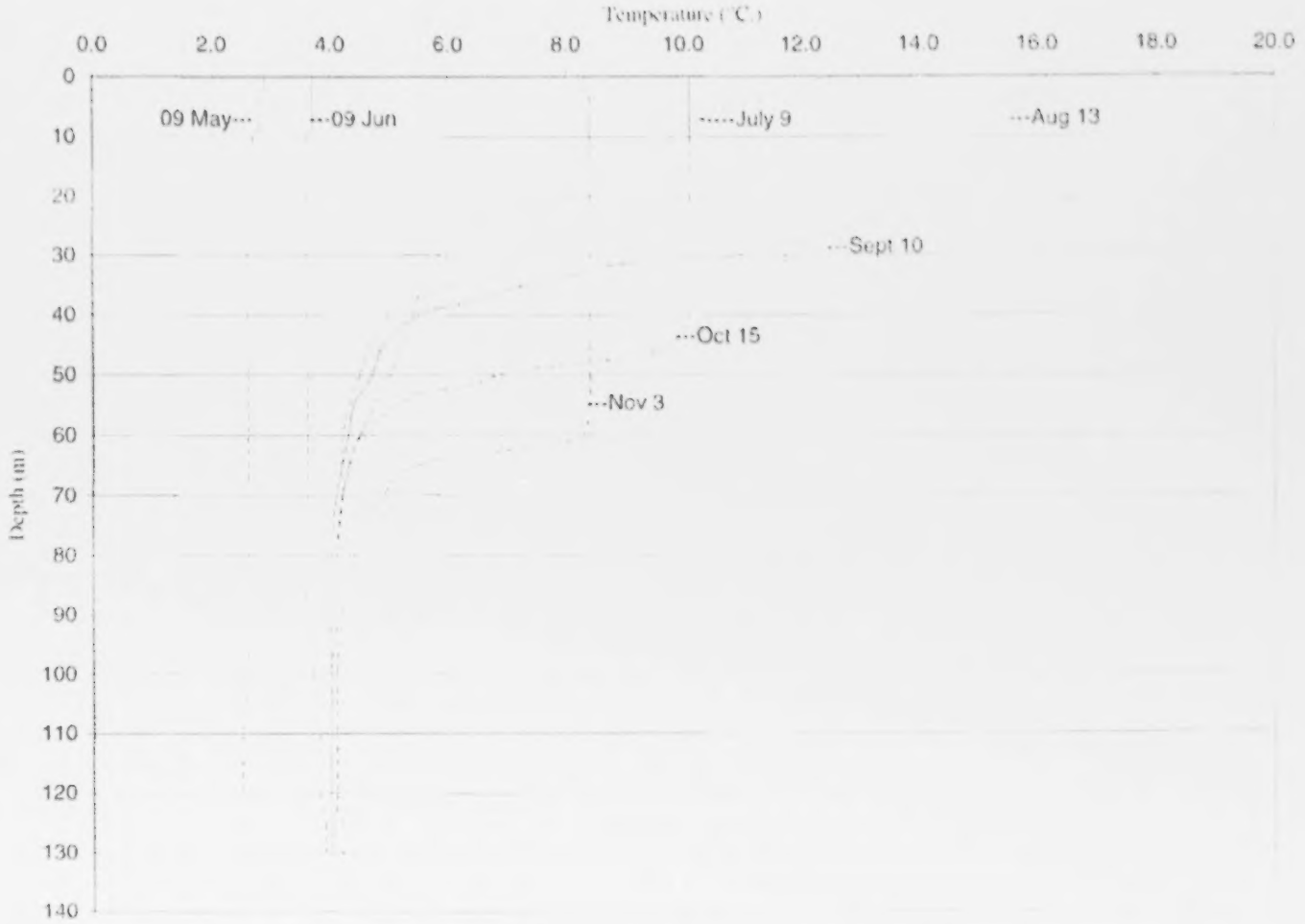
Parsnip Reach station (E234185) May to November 2000 temperature versus depth profile.



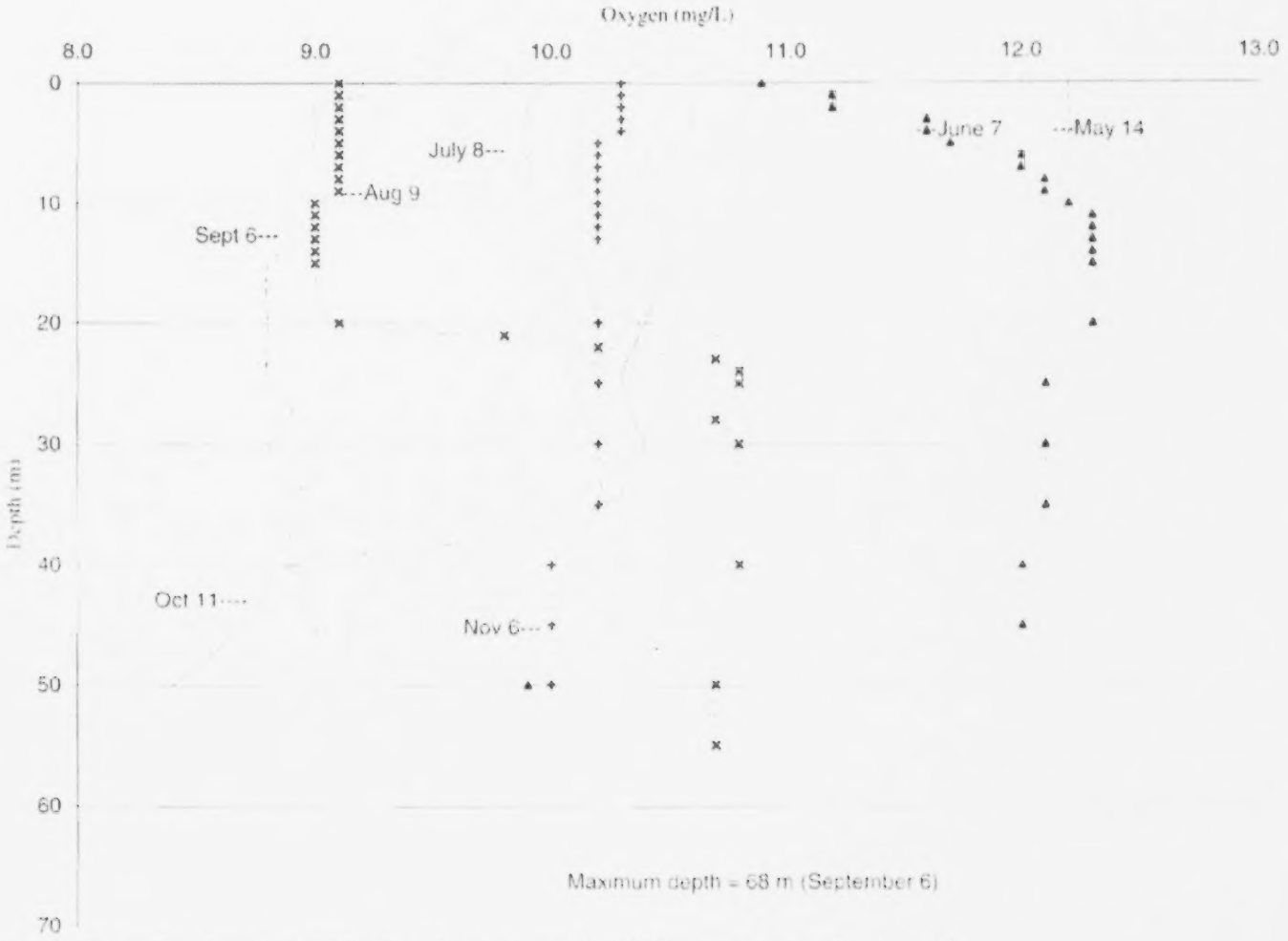
Peace Reach station (E234186) May to November 2000 temperature versus depth profile.



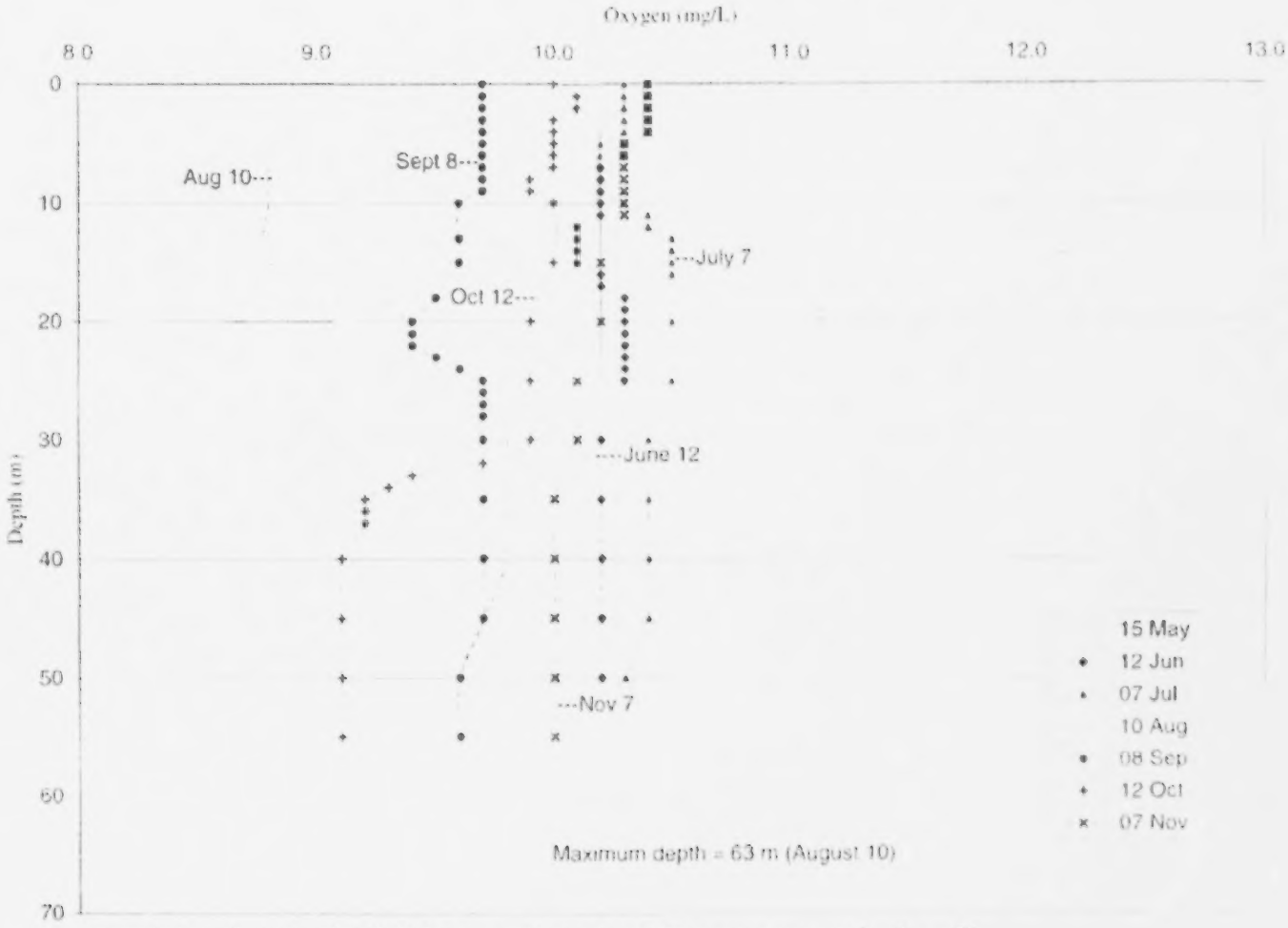
Junction station (E234187) May to November 2000 temperature versus depth profile.



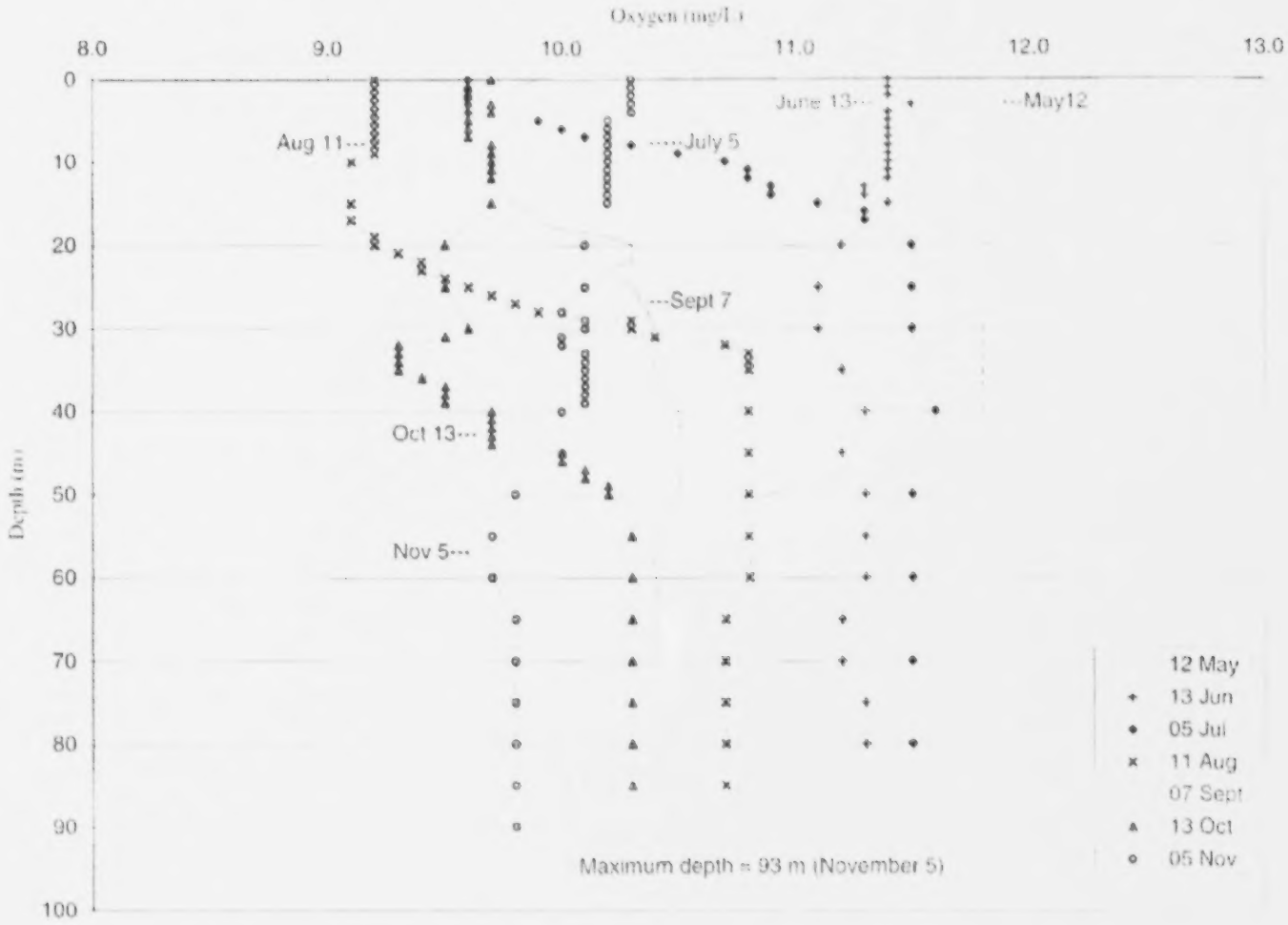
Forebay station (E234188) May to November 2000 temperature versus depth profile.



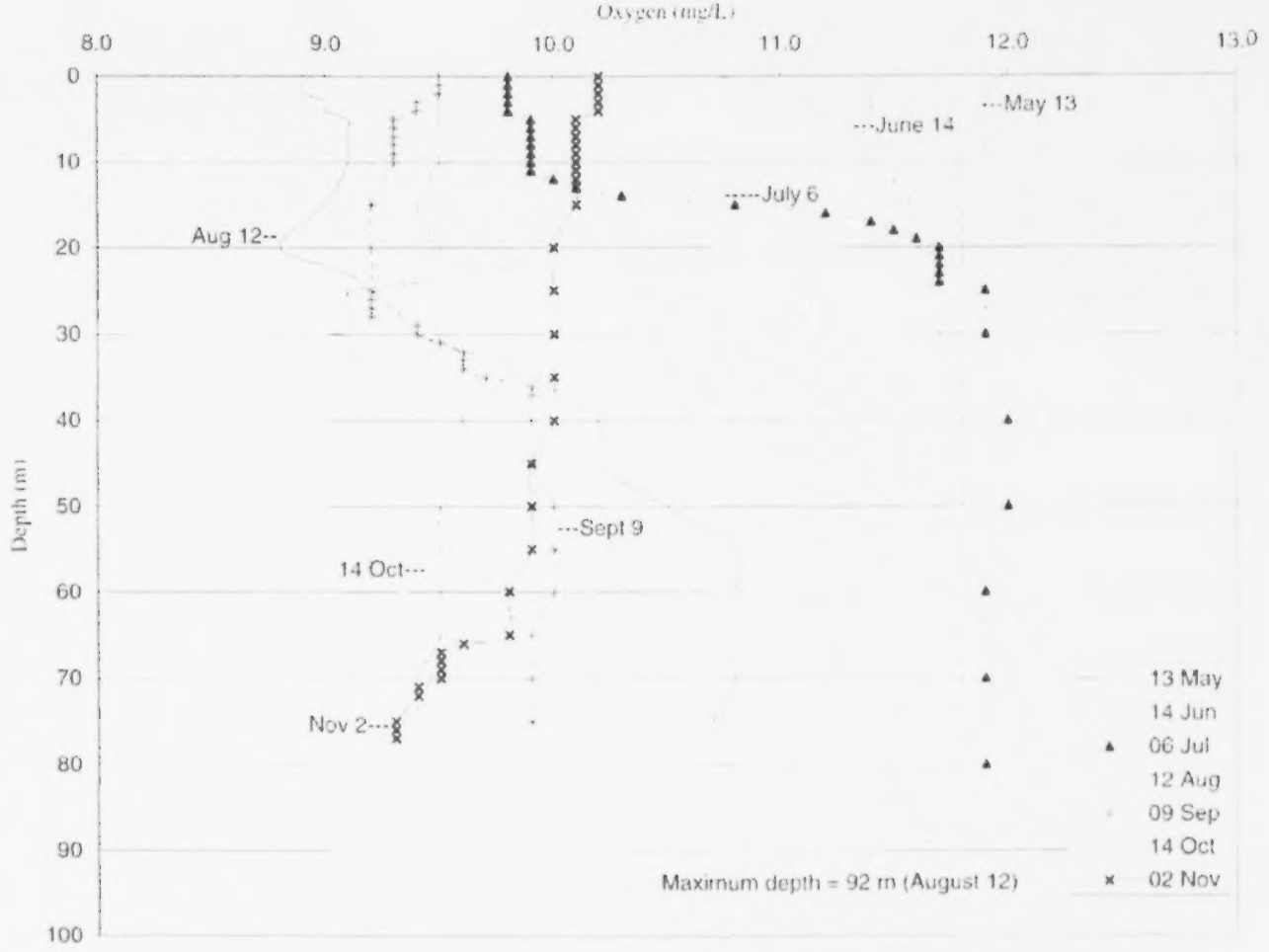
Finlay Reach station (E234184) May to November 2000 oxygen versus depth profile.



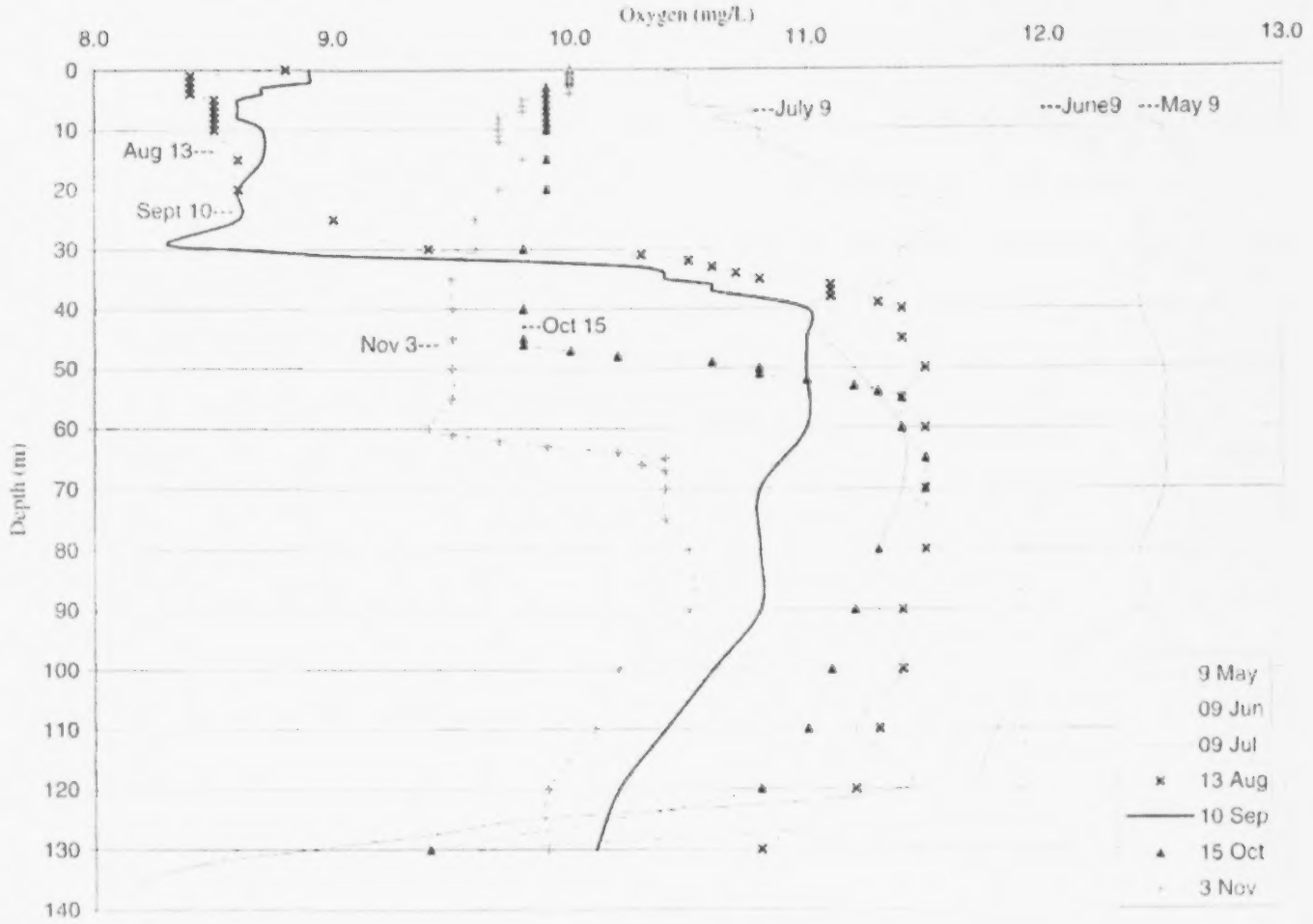
Parsnip Reach station (E234185) May to November 2000 oxygen versus depth profile.



Peace Reach station (E234186) May to November 2000 oxygen versus depth profile.



Junction station (E234187) May to November 2000 oxygen versus depth profile.



Forebay station (E234188) May to November 2000 oxygen versus depth profile.

Appendix C

(Monthly k values and water sample analysis results)

Light attenuation Coefficients for Williston Reservoir in May-November 2000.

	Parsnip	Finlay	Junction	Peace	Forebay
May	0.92	0.45	0.47	0.46	0.70
June	1.50	0.54	0.94	0.89	0.69
July	1.02	1.13	0.59	0.88	0.44
August	0.60	0.82	0.49	0.72	0.50
Sept.	1.26	0.77	0.97	0.66	0.98
Oct.	0.80	0.78	0.57	0.67	0.94
Nov.	0.80	0.74	0.78	0.66	0.71
Average	**0.99**	**0.75**	**0.69**	**0.71**	**0.71**

Key for water sample analysis results table

Date	Depth	Chl-a	NO3	TP	TDP	pH	TDS	S-D
1	2	3	4	5	6	7	8	9

1. Date- date samples were collected from Williston Reservoir.
2. Depth- depth (metres) sample was collected from.
3. Chl-a- Chlorophyll-a content (µg/L).
4. NO3- Nitrogen in the form of nitrite and nitrate (mg/L).
5. TP- Total phosphorous (mg/L).
6. TDP- Total dissolved phosphorous (mg/L).
7. pH- pH in field reading to nearest 0.1 value.
8. TDS- Total dissolved solids ,residue filterable (mg/L).
9. S-D- secchi disk depth recorded to nearest 0.1 m.

Mean values at the bottom of tables incorporate data collected from all Depths, with the exception of the nitrate (NO3) data. The mean value Presented represents the mean of the 1, 3, and 5 m samples only. The deep water nitrate values were not included the mean NO3 calculation.

EMS Site E234184 (Williston Reservoir, Finlay Reach)

Date	Depth	Chl-a	N03	TP	TDP	pH	TDS	S-D
14 May	1	1.1	0.028	0.003	0.002	8.3	140	6.0
14 May	3	0.5	0.028	0.004	< 0.002	8.2	130	
14 May	5	0.5	0.028	0.007	< 0.002	8.5	140	
14 May	30		0.029	0.004	<0.002	8.2	150	
7-Jun	1	2.1	0.025	0.016	0.003	8.3	110	3.8
7-Jun	1		0.025	0.016	0.007	8.3	110	
7-Jun	3	3.2	0.029	0.018	0.01	8.2	120	
7-Jun	5	3.7	0.029	0.016	0.012	8.2	120	
7-Jun	30		0.034	0.015	0.006	8.1	110	
8-Jul	1	2.1	0.014	0.011	0.004	8.4	120	2.1
8-Jul	3	2.1	0.014	0.01	0.004	8.5	130	
8-Jul	5	2.7	0.014	0.011	0.005	8.4	120	
8-Jul	30		0.043	0.007	0.005	8.1	130	
9-Aug	1	1.1	0.003	0.009	0.006	8.4	120	4.4
9-Aug	3	1.6	0.003	0.01	0.006	8.6	130	
9-Aug	5	1.1	0.003	0.008	0.006	8.6	120	
9-Aug	5		0.003	0.011	0.005	8.6	120	
9-Aug	50		0.044	0.006	0.006	8.2	130	
6-Sep	1	1.6	0.007	0.01	0.005	8.7	110	4
6-Sep	3	1.6	0.007	0.018	0.006	8.7	110	
6-Sep	5	1.6	0.008	0.009	0.005	8.6	110	
6-Sep	50		0.052	0.006	0.006	8.2	140	
10-Oct	1	<0.4	0.012	0.01	0.007	8.7	110	3.9
10-Oct	3	<0.4	0.007	0.01	0.004	8.6	110	
10-Oct	5	<0.4	0.006	0.009	0.005	8.6	110	
10-Oct	40		0.05	0.01	0.006	8.2	130	
6-Nov	1	1.6	0.022	0.005	0.006	8.6	110	3.6
6-Nov	1		0.021	0.005	0.007	8.6	120	
6-Nov	3	2.1	0.021	0.005	0.006	8.5	120	
6-Nov	5	1.6	0.021	0.005	0.006	8.5	110	
6-Nov	40		0.022	0.005	0.006	8.6	120	
Mean		1.6	0.0156	0.0092	0.0054	8.4	122	4.0

EMS Site E234185 (Williston Reservoir, Parsnip Reach)

Date	Depth	Chl-a	NO3	TP	TDP	pH	TDS	S-D
15 May	1	1.1	0.142	0.013	0.007	8.1	100	3.7
15 May	3	0.5	0.142	0.008	0.006	8	130	
15 May	5	1.1	0.142	0.009	0.006	7.9	120	
15 May	30		0.142	0.009	0.007	8	120	
12 Jun	1	2.1	0.198	0.01	-	8.7	80	2.6
12 Jun	1		0.195	0.009	0.006	8.7	80	
12 Jun	3	2.1	0.193	0.01	0.006	8.4	80	
12Jun	5	2.1	0.198	0.009	0.005	8.5	80	
12 Jun	30		0.16	0.009	0.009	7.9	120	
07 Jul	1	1.1	0.122	0.008	0.004	8.2	80	4.1
07 Jul	3	0.5	0.122	0.008	0.006	8.2	80	
07 Jul	5	1.6	0.121	0.008	0.004	8.1	80	
07 Jul	30		0.126	0.007	0.005	7.9	100	
10 Aug	1	2.1	0.03	0.008	0.007	8.5	70	3.5
10 Aug	3	3.2	0.03	0.009	0.006	8.5	70	
10 Aug	5	3.7	0.03	0.01	0.006	8.5	80	
10 Aug	5		0.03	0.009	0.006	8.5	70	
10 Aug	50		0.126	0.007	0.006	8	90	
08 Sep	1	1.6	0.066	0.008	0.006	8.4	90	5
08 Sep	3	1.6	0.067	0.008	0.006	8.3	80	
08 Sep	5	1.6	0.068	0.009	0.005	8.3	100	
08 Sep	50		0.088	0.006	0.005	8	110	
12 Oct	1	1.6	0.081	0.007	0.004	8.4	90	5.4
12 Oct	3	1.6	0.081	0.01	0.005	8.4	90	
12 Oct	5	1.6	0.081	0.007	0.004	8.5	100	
12 Oct	40		0.094	0.006	0.005	8.1	100	
07 Nov	1	<0.4	0.096	0.005	0.006	8.5	90	4.2
07 Nov	1	-	0.096	0.005	0.006	8.5	100	
07 Nov	3	0.5	0.095	0.005	0.005	8.4	100	
07 Nov	5	0.5	0.097	0.005	0.005	8.3	100	
07 Nov	40		0.095	0.005	0.006	8.3	100	
Mean=		1.5	0.1048	0.0079	0.0056	8.3	94	4.1

EMS Site E234186 (Williston Reservoir, Peace Reach, Clearwater)

Date	Depth	Chl-a	NO3	TP	TDP	pH	TDS	S-D
12 May	1	1.1	0.06	0.006	0.003	8.2	110	5.2
12 May	3	0.5	0.057	0.005	0.002	8.2	120	
12 May	5	0.5	0.059	0.006	0.002	8.2	110	
12 May	30		0.063	0.006	0.004	8.1	110	
13 Jun	1	0.5	0.092	0.006	0.003	8.2	120	3.0
13 Jun	3	1.1	0.094	0.005	0.003	8.2	120	
13 Jun	5	1.1	0.088	0.006	0.004	8.1	100	
13 Jun	30		0.074	0.003	0.004	7.9	120	
05 Jul	1	2.1	0.089	0.012	0.005	8.4	100	5.1
05 Jul	3	1.6	0.089	0.009	0.005	8.6	100	
05 Jul	5	0.5	0.09	0.007	0.006	8.4	110	
05 Jul	30		0.068	0.006	0.005	8.1	120	
11 Aug	1	2.1	0.046	0.007	0.007	8.6	70	5.5
11 Aug	3	2.1	0.046	0.007	0.006	8.6	90	
11 Aug	5	2.7	0.046	0.009	0.005	8.5	90	
11 Aug	50		0.081	0.006	0.004	8.2	110	
07 Sep	1	1.1	0.05	0.009	0.003	8.6	110	4.2
07 Sep	1		0.048	0.007	0.006	8.6	100	
07 Sep	3	1.1	0.057	0.007	0.003	8.5	100	
07 Sep	5	2.1	0.049	0.007	0.007	8.4	100	
07 Sep	50		0.076	0.006	0.007	8.2	120	
13 Oct	1	0.5	0.052	0.007	0.004	8.4	90	5.3
13 Oct	3	1.1	0.052	0.008	0.004	8.4	100	
13 Oct	3		0.05	0.005	0.005	8.4	90	
13 Oct	5	1.1	0.051	0.01	0.005	8.4	100	
13 Oct	50		0.082	0.007	0.004	8.3	110	
02 Nov	1	1.6	0.064	<0.002	<0.002	8.6	100	6.4
02 Nov	3	1.6	0.063	<0.002	<0.002	8.5	100	
02 Nov	5	0.5	0.065	0.002	<0.002	8.5	100	
02 Nov	50		0.075	0.002	<0.002	8.5	110	
Mean=		1.3	0.0646	0.0062	0.0041	8.4	105	5

EMS Site E234187 (Williston Reservoir, Junction)

Date	Depth	Chl-a	N03	TP	TDP	pH	TDS	S-D
13 May	1	2.1	0.063	0.008	0.009	8.3	100	3.7
13 May	1		0.063	0.006	0.003	8.3	110	
13 May	3	1.1	0.062	0.014	0.009	8.1	110	
13 May	5	1.6	0.06	0.006	0.004	8.1	110	
13 May	30		0.061	0.009	0.003	8.1	110	
14 Jun	1	1.6	0.093	0.006	0.003	8.2	110	2.7
14 Jun	3	1.6	0.091	0.006	0.002	8.1	110	
14 Jun	5	1.6	0.09	0.007	0.003	8.1	110	
14 Jun	30		0.073	0.005	0.002	8.2	110	
06 Jul	1	0.5	0.068	0.009	0.004	8.5	90	2.2
06 Jul	3	1.1	0.065	0.011	0.004	8.4	100	
06 Jul	3		0.064	0.01	0.004	8.4	90	
06 Jul	5	1.1	0.066	0.01	0.005	8.4	90	
06 Jul	30		0.074	0.005	0.003		110	
12 Aug	1	2.1	0.038	0.009	0.005	8.5	80	3.5
12 Aug	3	2.7	0.039	0.009	0.005	8.8	90	
12 Aug	5	5.3	0.046	0.009	0.005	8.4	80	
12 Aug	50		0.086	0.005	0.005	8.2	100	
09 Sep	1	0.5	0.037	0.008	0.005	8.5	100	3.5
09 Sep	1		0.037	0.008	0.006	8.5	100	
09 Sep	3	2.1	0.038	0.008	0.005	8.4	100	
09 Sep	5	0.5	0.037	0.008	0.006	8.4	100	
09 Sep	50		0.07	0.006	0.006	8.1	130	
14 Oct	1	1.1	0.047	0.007	0.007	8.6	100	3.6
14 Oct	3	1.1	0.047	0.008	0.004	8.6	90	
14 Oct	5	1.1	0.049	0.007	0.003	8.6	100	
14 Oct	50		0.087	0.005	0.004	8.2	120	
08 Nov	1	0.5	0.061	0.006	0.005	8.5	110	3.5
08 Nov	3	0.5	0.061	0.007	0.004	8.5	110	
08 Nov	5	1.1	0.061	0.006	0.005	8.5	110	
08 Nov	50		0.061	0.006	0.004	8.5	110	
Mean=		1.5	0.0580	0.0074	0.0045	8.4	103	3.5

EMS Site E234188 (Williston Reservoir, Peace Reach, Forebay)

Date	Depth	Chl-a	NO3	TP	TDP	pH	TDS	S-D
09 May	1	1.1	0.073	0.005	0.004	8.3	110	5.5
09 May	1		0.072	0.005	0.004	8.3	140	
09 May	3	0.5	0.072	0.005	0.004	8.4	130	
09 May	5	1.6	0.071	0.006	0.002	8.4	130	
09 May	20		0.072	0.005	0.004	8.7	130	
09 Jun	1	< 0.8	0.072	0.004	< 0.002	8.3	120	4.3
09 Jun	1		0.072	0.004	0.003	8.3	110	
09 Jun	3	2.1	0.072	0.003	< 0.002	8	130	
09 Jun	5	2.1	0.073	0.004	0.005	8.1	120	
09 Jun	30		0.072	0.004	< 0.002	8	120	
09 Jul	1	<0.04	0.067	0.011	0.005	8.5	100	4.1
09 Jul	3	1.1	0.068	0.009	0.005	8.4	110	
09 Jul	3		0.068	0.011	0.003	8.4	100	
09 Jul	5	<0.04	0.068	0.008	0.004	8.4	110	
09 Jul	30		0.063	0.006	0.006	8.3	120	
13 Aug	1	1.1	0.058	0.008	0.005	8.6	90	5.6
13 Aug	3	<0.4	0.057	0.011	0.002	8.6	90	
13 Aug	5	3.7	0.058	0.008	0.006	8.6	100	
13 Aug	50		0.076	0.002	0.005	8.3	100	
10 Sep	1	1.6	0.06	0.008	0.006	8.6	110	1.9
10 Sep	3	1.6	0.058	0.009	0.006	8.6	100	
10 Sep	5	2.1	0.059	0.009	0.006	8.6	110	
10 Sep	50		0.074	0.007	0.006	8.3	130	
15 Oct	1	0.5	0.066	0.01	0.003	8.6	100	2.4
15 Oct	3	0.5	0.064	0.009	0.003	8.6	100	
15 Oct	3		0.066	0.009	0.004	8.5	110	
15 Oct	5	1.1	0.064	0.008	0.003	8.5	100	
15 Oct	50		0.086	0.011	0.005	8.5	110	
03 Nov	1	1.1	0.073	0.002	<0.002	8.6	90	4.7
03 Nov	3	0.5	0.073	0.002	<0.002	8.6	90	
03 Nov	5	0.5	0.076	0.002	<0.002	8.6	100	
03 Nov	50		0.076	0.003	<0.002	8.6	100	
Mean=		1.1	0.0668	0.0064	0.0039	8.4	109	4.1